Fermilab

Beam-Beam Phenomena in Tevatron and Need in Better Understanding

Vladimir Shiltsev

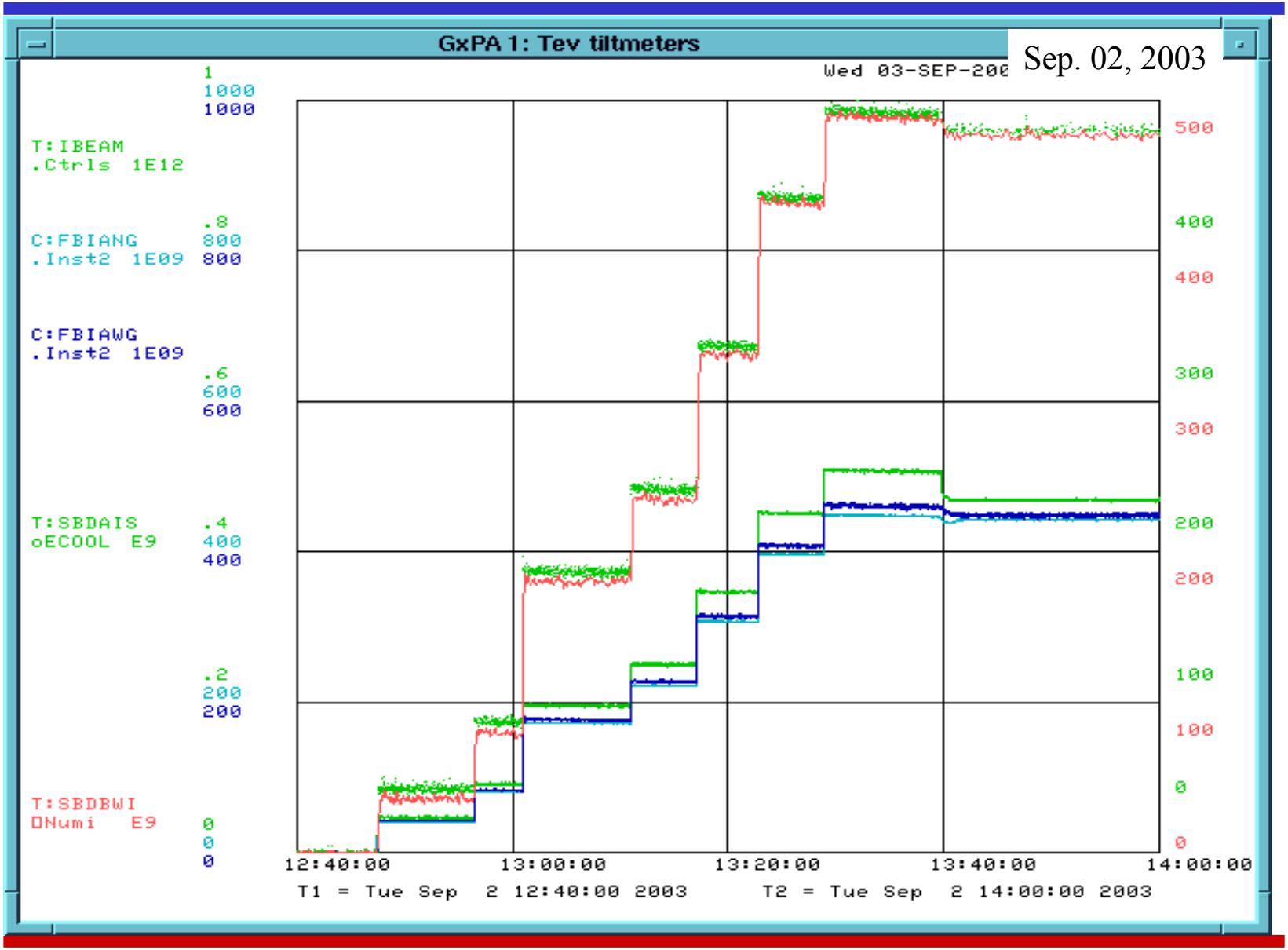
Tevatron Beam-Beam List

- Sqrt(Time) at 150
- Cogging effects at 150
- Loss on ramp
- Reduced eff.emittance and luminosity lifetime
- "Scallops"
- Poor proton lifetime due to IP size mismatch
- Longitudinal IP position effect
- Losses vs crossing angle and separation at IP
- Lifetime(s) vs helix size

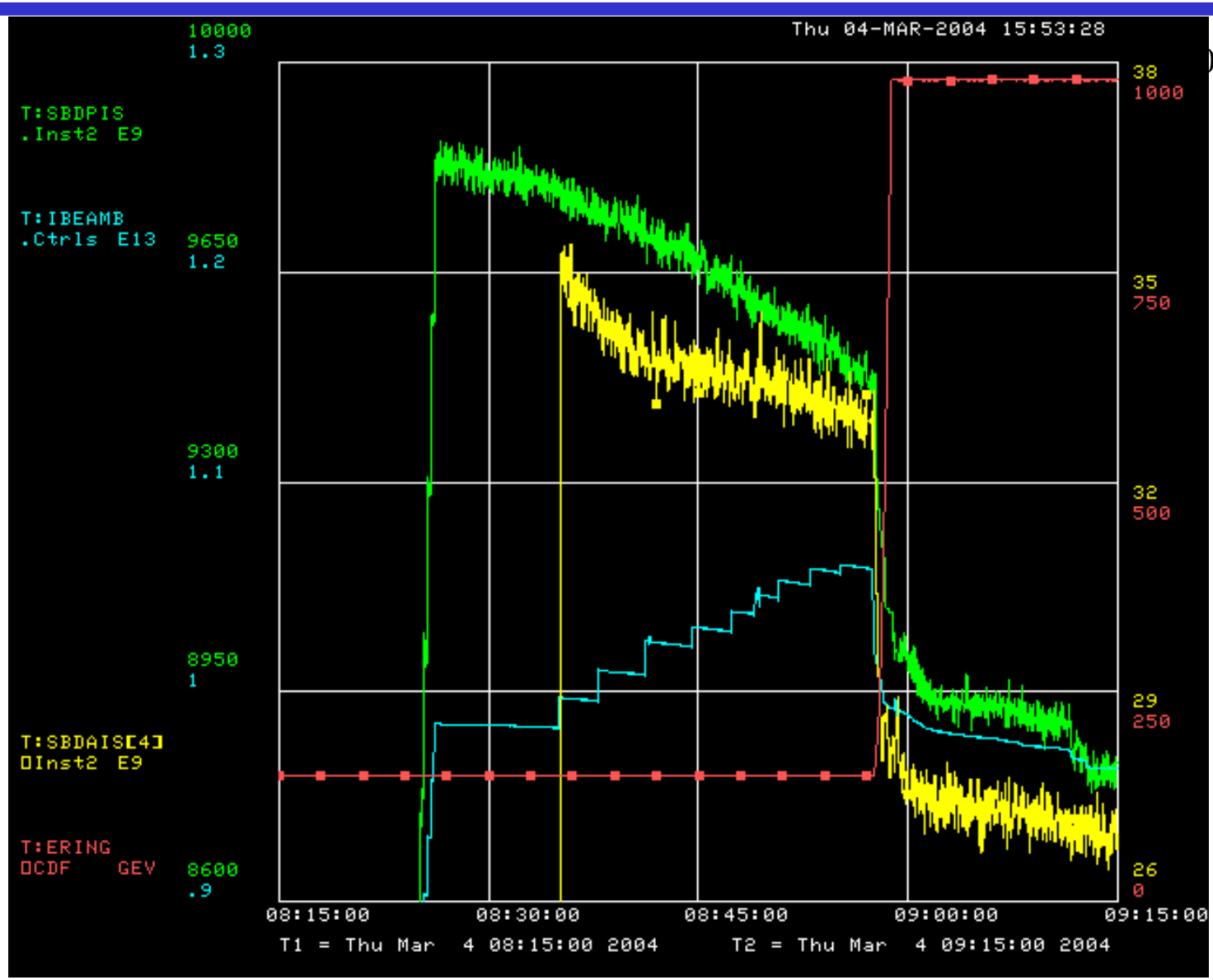
Fight for better Tevatron

	10/02	03/03	09/03	02/04	p/p only
Record Luminosity, e30	36	41	50	63	n/a
Protons/bunch	170e9	205e9	245e9	245e9	same
Pbars/bunch	22e9	23e9	25e9	30e9	same
P-loss at 150 GeV	14%	10%	8%	5%	5%
Pbar-loss at 150	9%	4%	2%	2%	2%
P-loss on ramp	6%	5%	5%	4%	3% *
Pbar-loss on ramp	8%	11%	8%	6%	2%
Pbar-loss in squeeze	5%	2%	3%	1%	0%
… at the beginning of store:					
Pbar lifetime at HEP, hr	~40	~35	~35	~30	~900
Proton lifetime at HEP, hr	~90	~60	~20	~100	~300 *
Eff.emittance lifetime, hr	~14	~26	~31	~16	n/a
Luminosity lifetime, hr	~10	~13	~10	~9	n/a

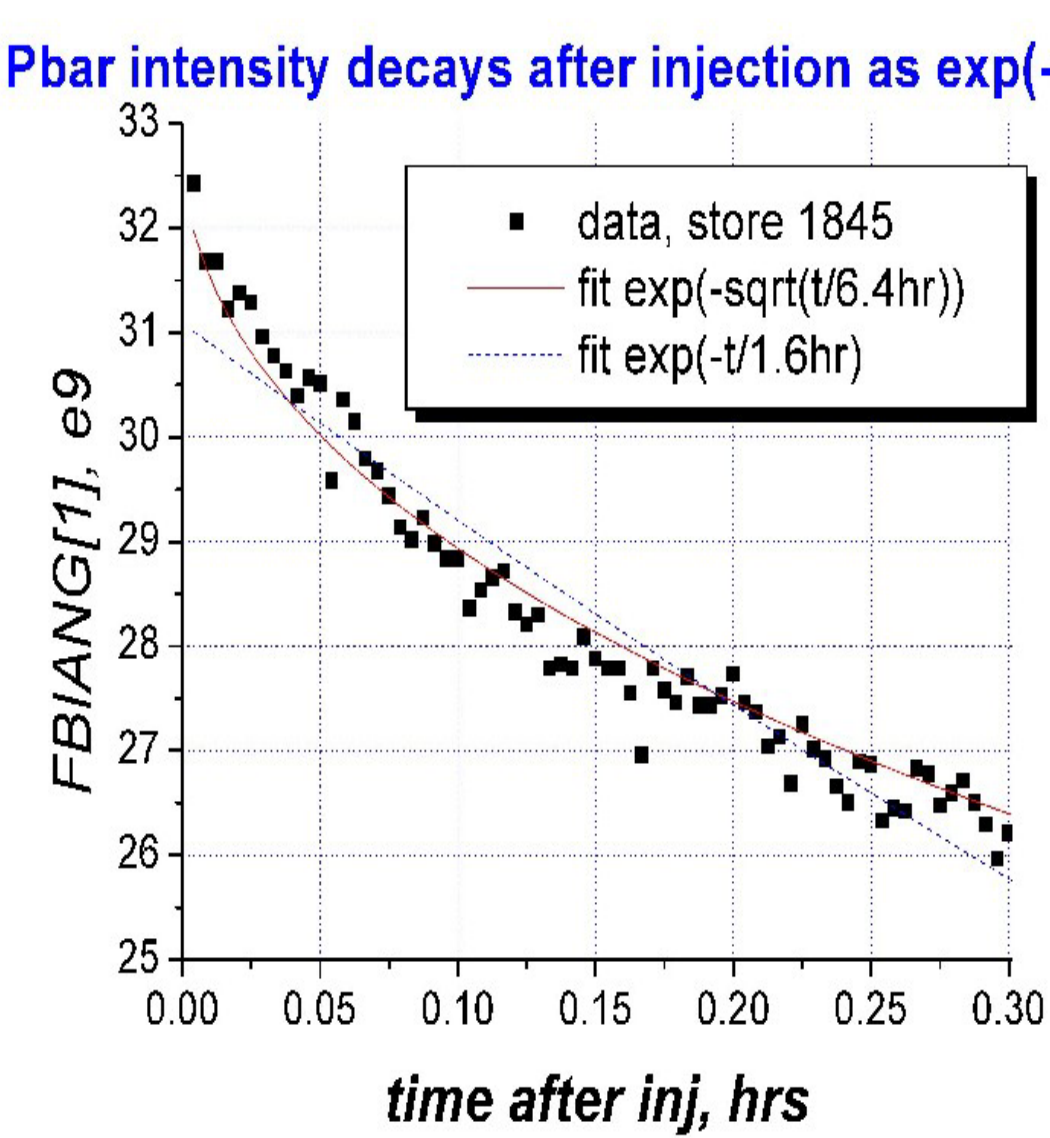
Pbar Only Store: <4% loss from Inj to LB



Pbar Losses: sqrt(time), cogging, ramp; P-loss



Beam-Beam @ Injection: Shaving

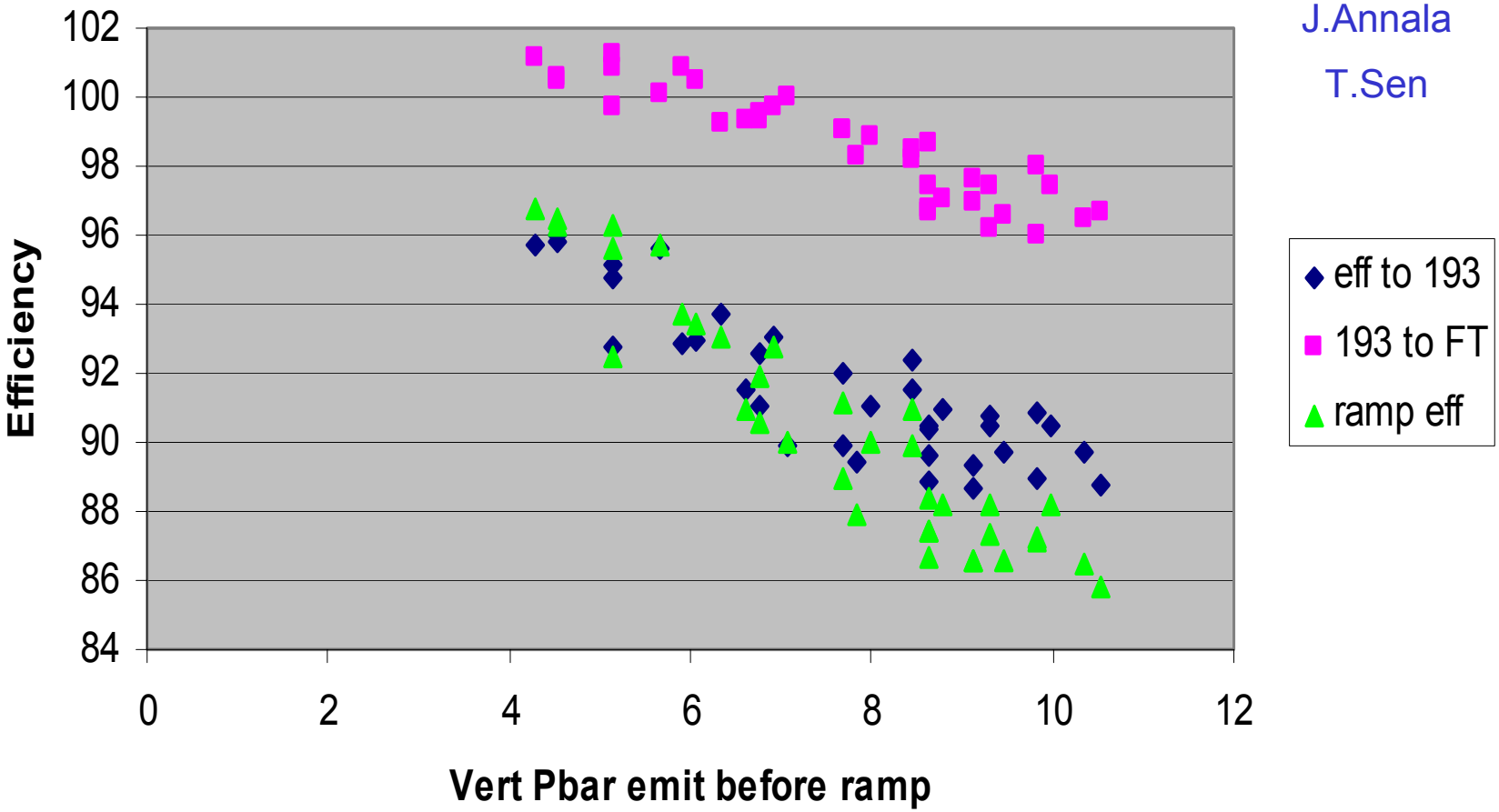


- dN_pbar scales approx. as
  - **Sqrt(time)**
  - **Chromaticity^*a*, *a*=1..2**
  - **N_protons^*b*, *b*=0.5…1 (?)**

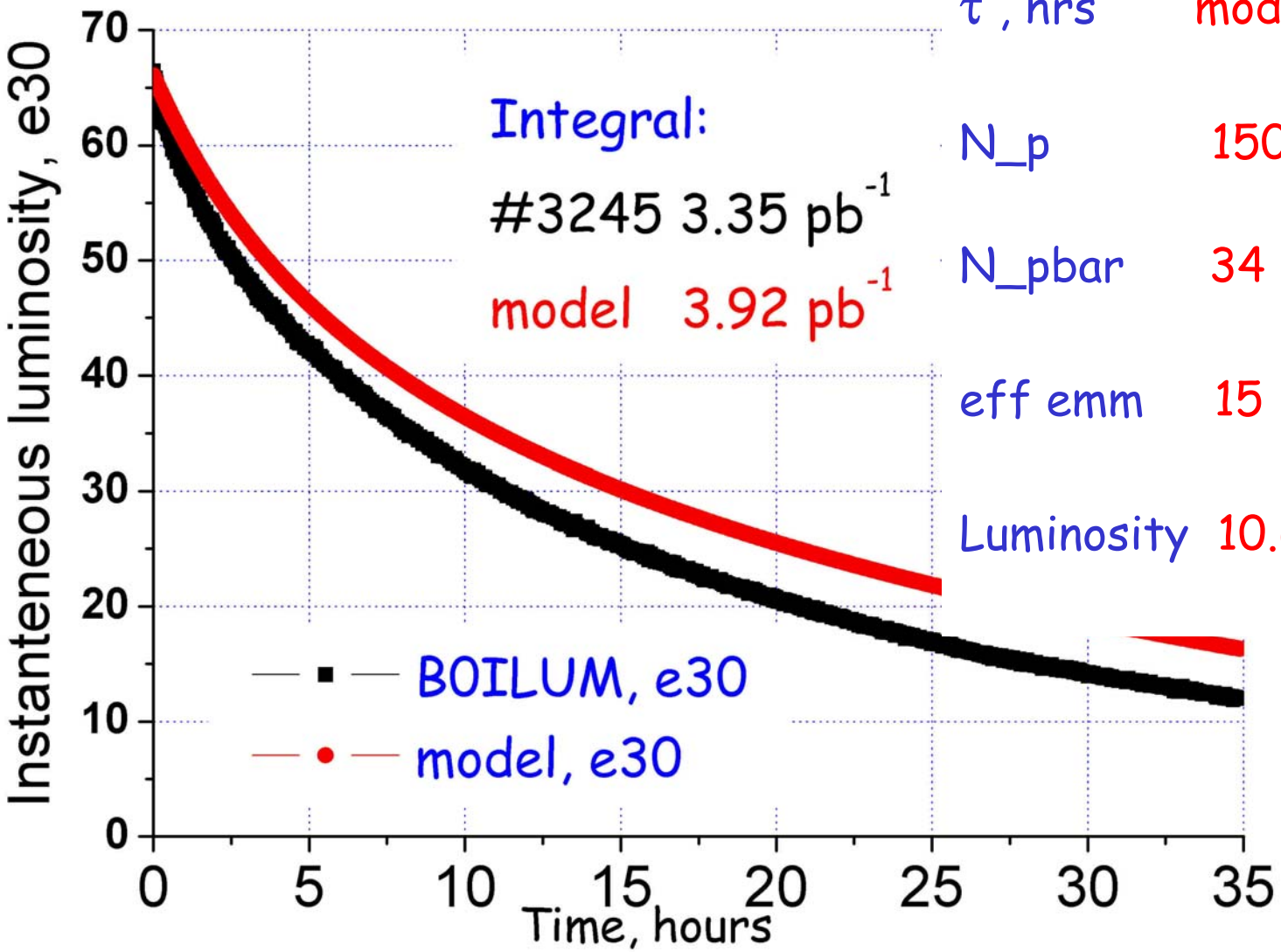
Also

- **Larger for larger emittance**
- **Larger for larger dp/p**

Pbar Loss on Ramp: Aperture+Emittance+Beam-Beam



Model w/o Beam-Beam and Store 3245



τ , hrs	model	#3245
N_p	150	150
N_pbar	34	32
eff emm	15	12
Luminosity	10.6±1	8.2

Beam-Beam Tune Shifts

$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p}$$

head-on tune shift per IP, now with N_p=245e9 and 95% emittance 20p

total max head-on tuneshift is 0.018 for pbars, 0.004 for protons

tune shift for separated beams is smaller:

$$\Delta\nu = \sum_i \frac{\beta_i N_p r_p}{2\gamma\pi d_i^2} = \sum_i \frac{2\xi}{(d_i/\sigma_i)^2}$$

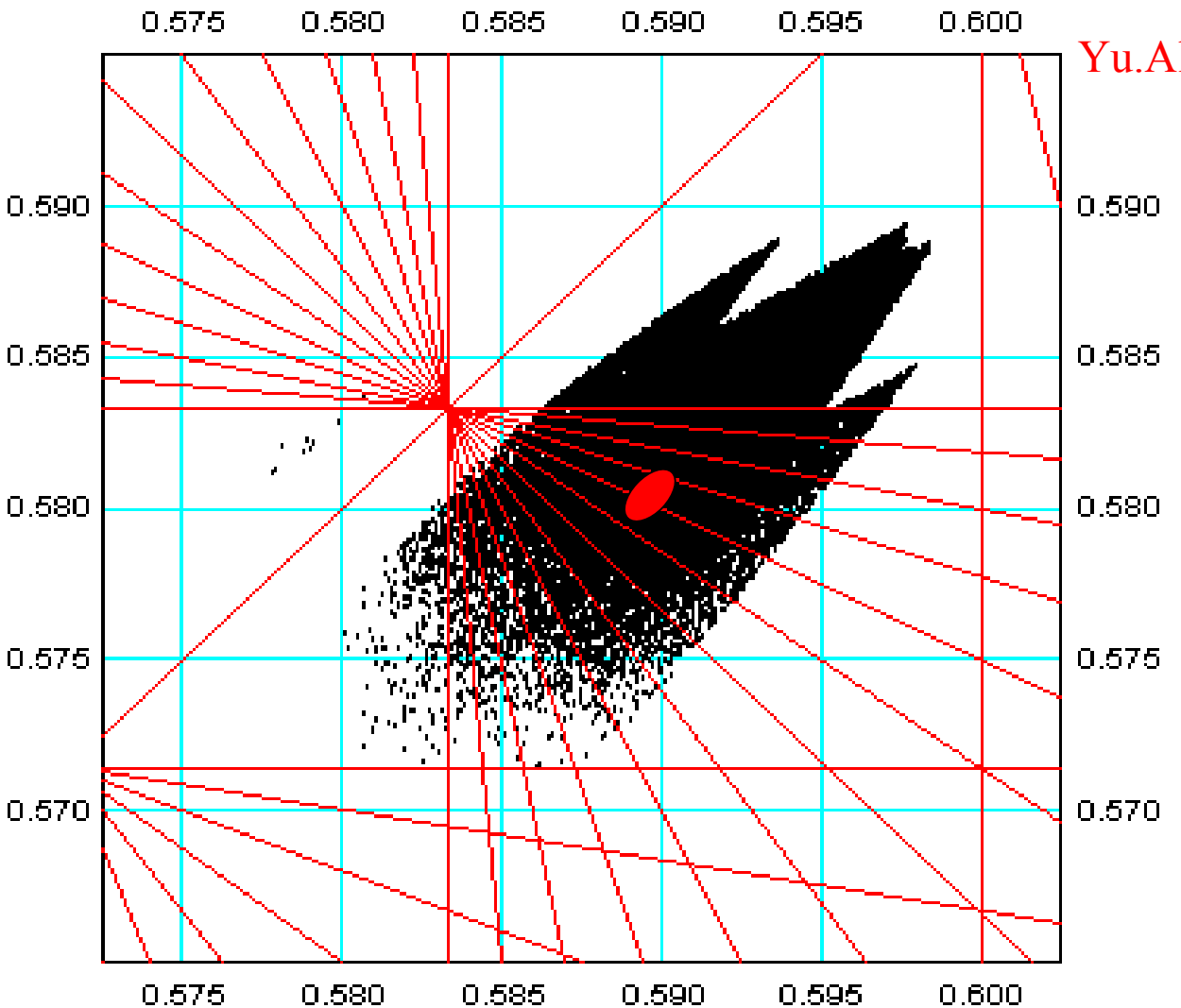
but: a) always present

b) MANY near-misses i = 70

c) different bunch-by-bunch

d) HV separator limited: gd^2 scales as V^2 / g

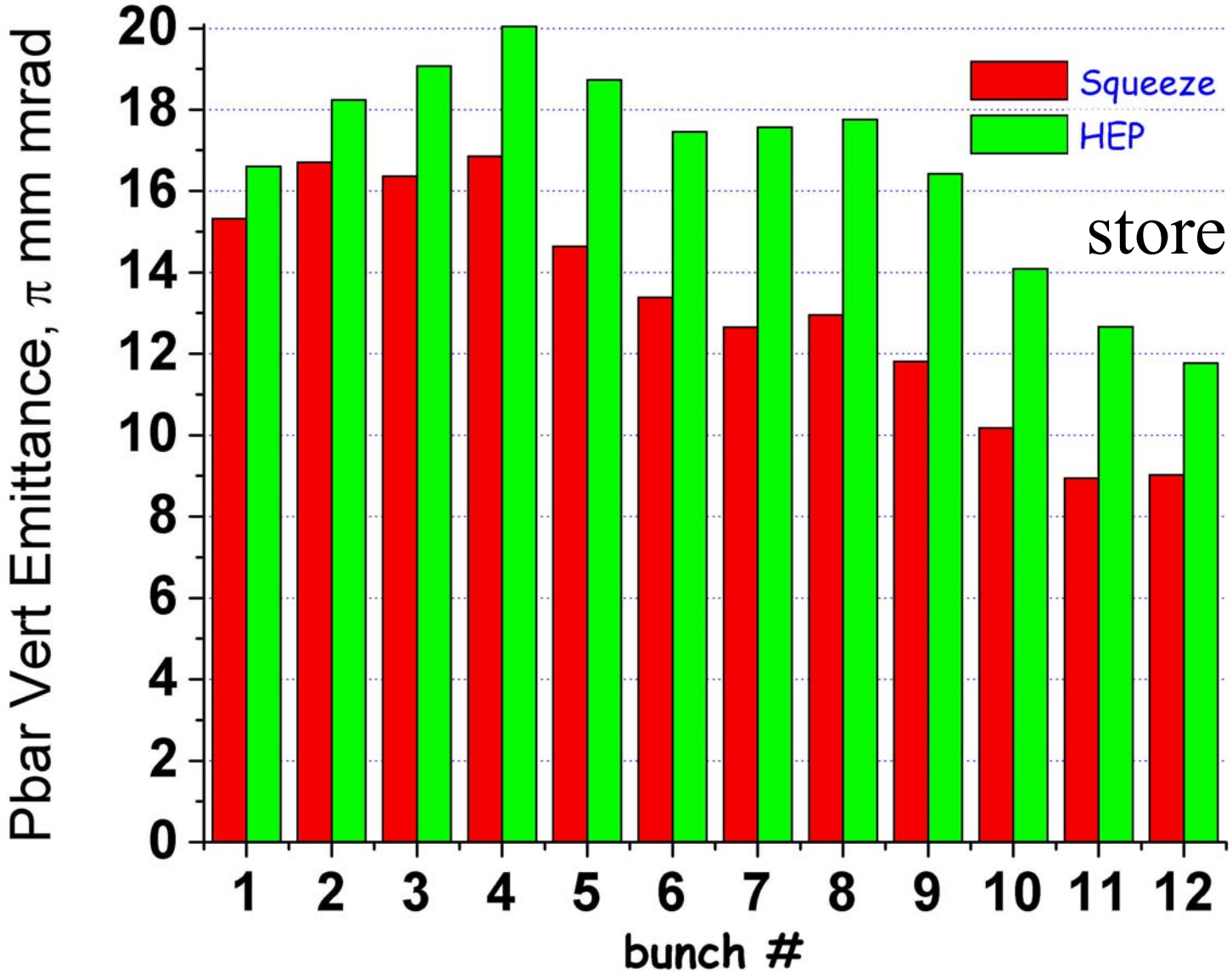
Tevatron Working Points



Yu.Alexahin

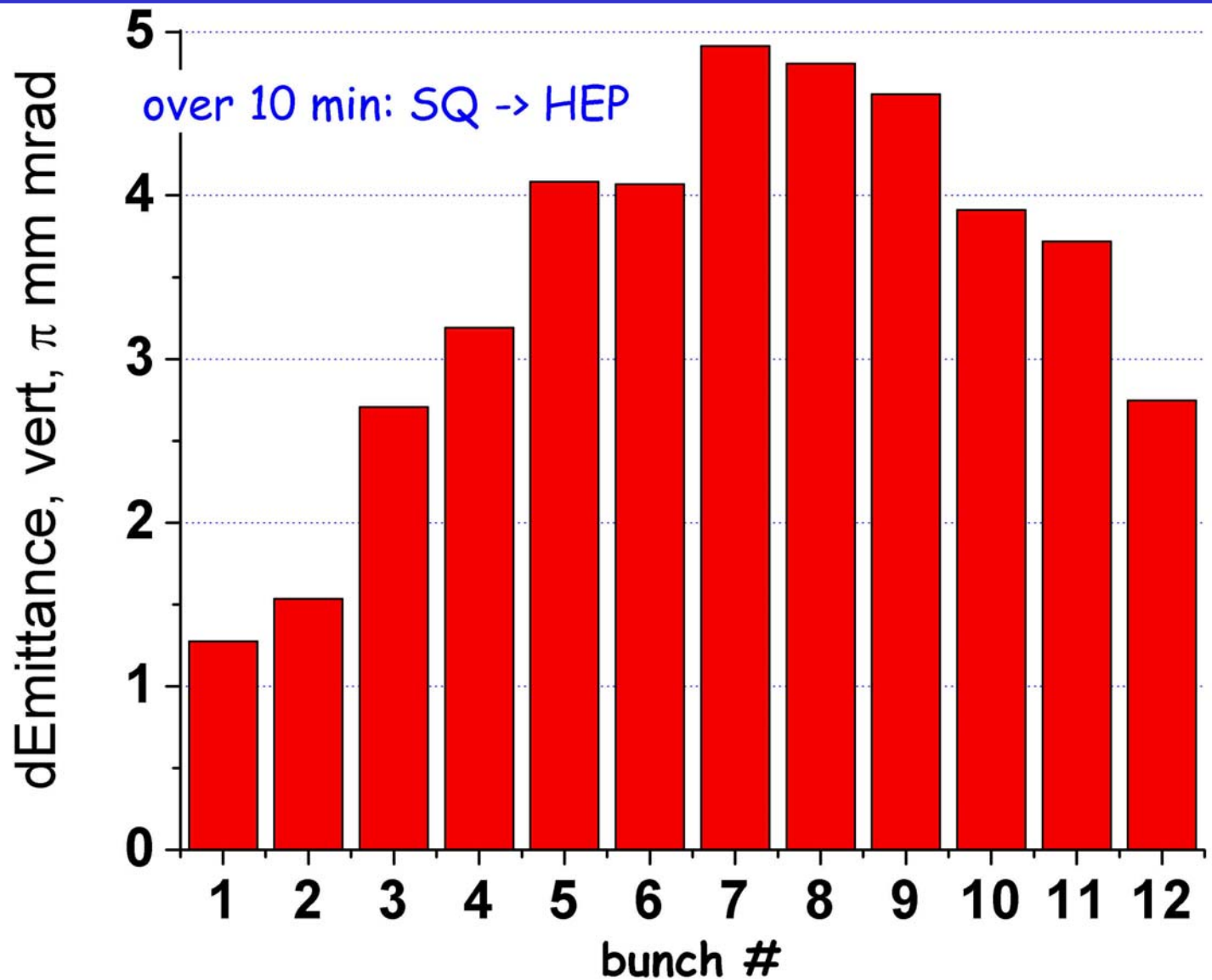
Protons: 20 π
250e9/bunch

Evolution of Pbar Emittance

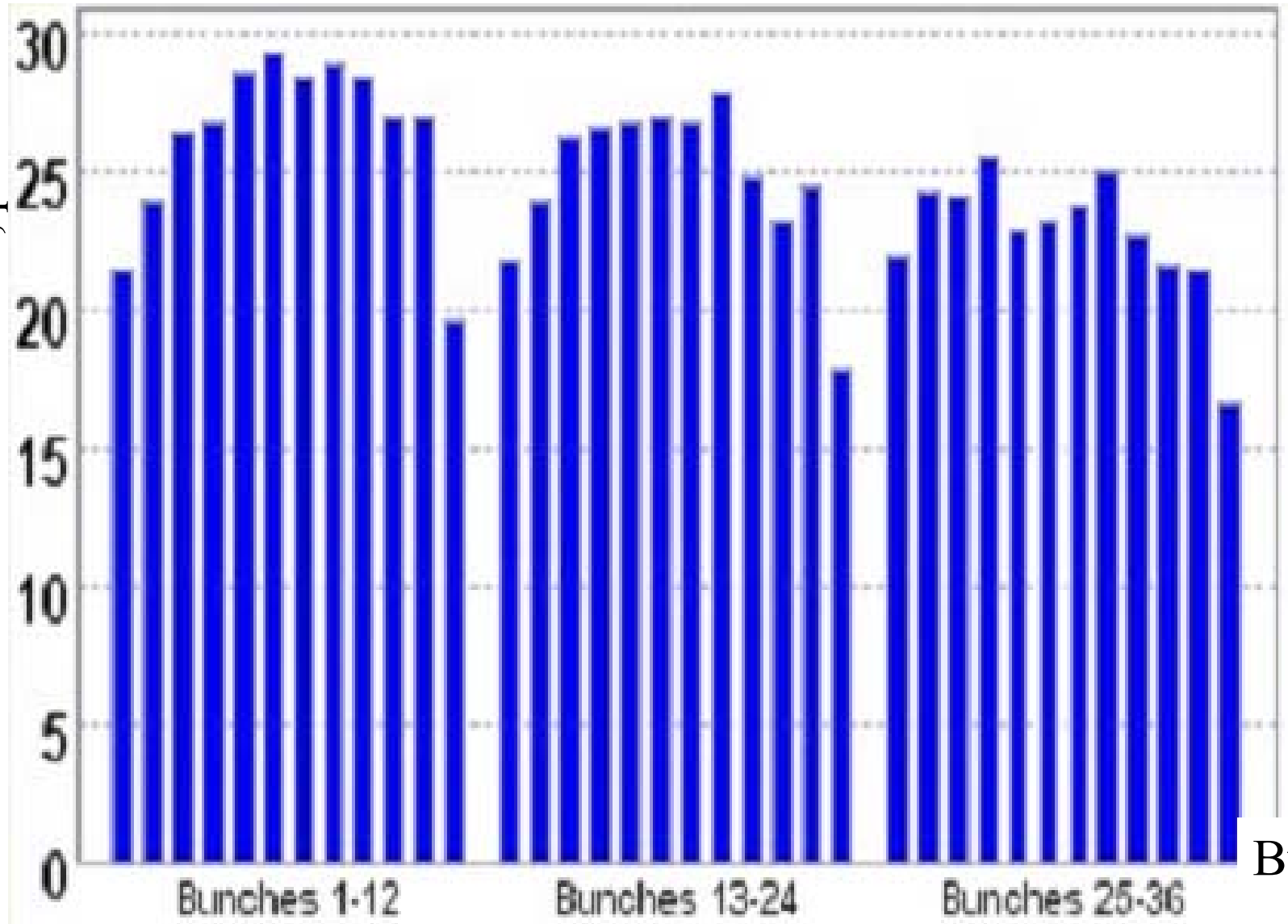


store #3231

Pbar Bunch Emittance Growth



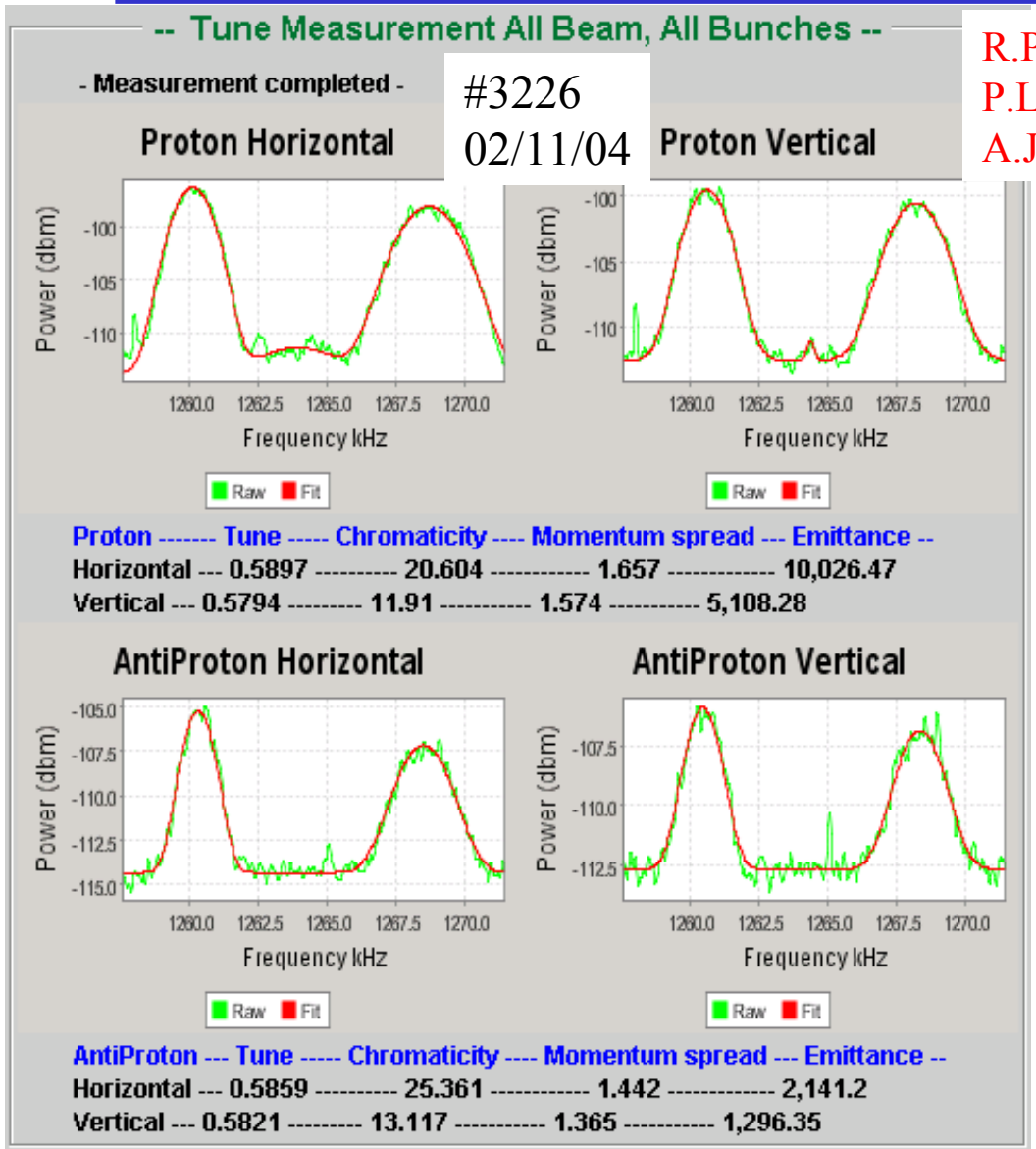
"Scallops" in Pbar Bunch Emittances



Facts about "Scallops"

- "Scallops" is beam-beam phenomenon, started to occur after N_protons exceeded 180e9/bunch in ~Jan 2003, do not take place in every store even with N_p >180e9/bunch
- "Scallops" occur in both planes, but often more prominent in vertical
- Duration of faster emittance growth is 15-60 min
- Pbar emittance does not exceed the proton one
- "Scallops" are dependent on tunes, strong near Q=0.6; vertical tune change –0.002 can significantly reduce scallops, that has also been confirmed by TEL studies.
- Small "scallops" were seen in protons
- Scallops are the same in all three trains of bunches (vary <20%)

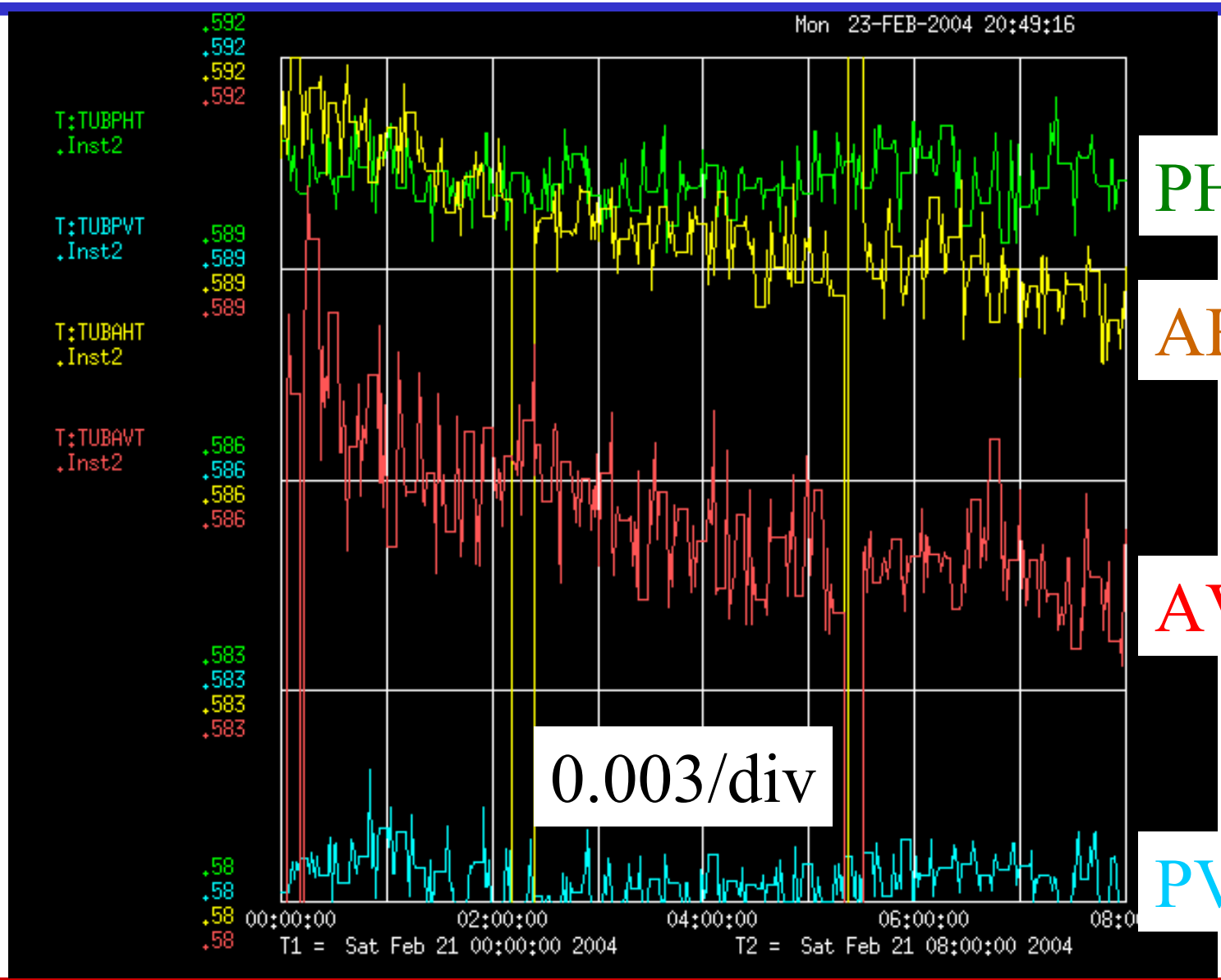
1.7GHz Schottky Spectra



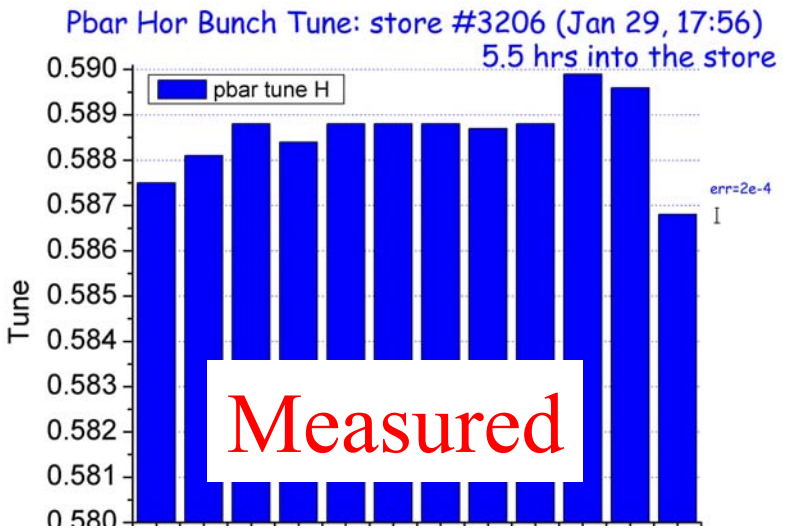
R.Pasquinelli
P.Lebrun
A.Jansson

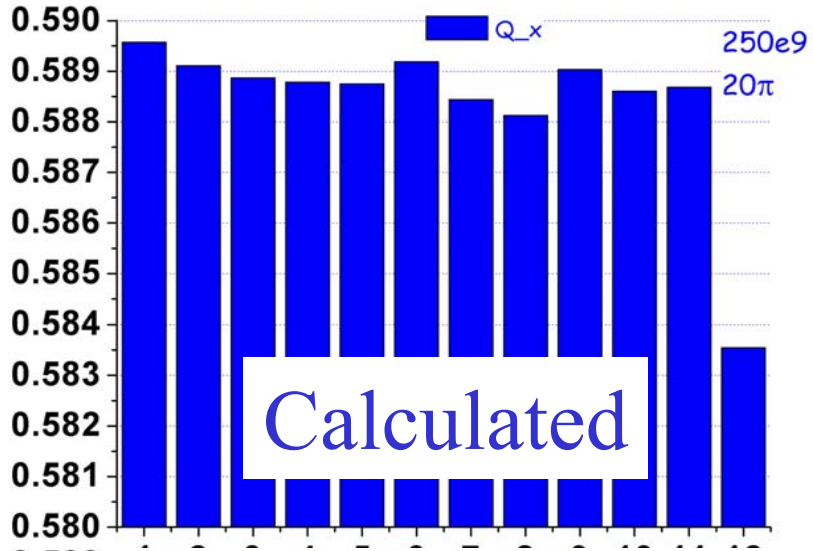
- Q and 1-Q lines are seen
- Fit gives:
  - Betatron frequency
  - dP/P ∝ sum of two widths
  - C_vh ∝ difference of two widths
  - Emittance ∝ area under the peaks
- Can do that for each bunch

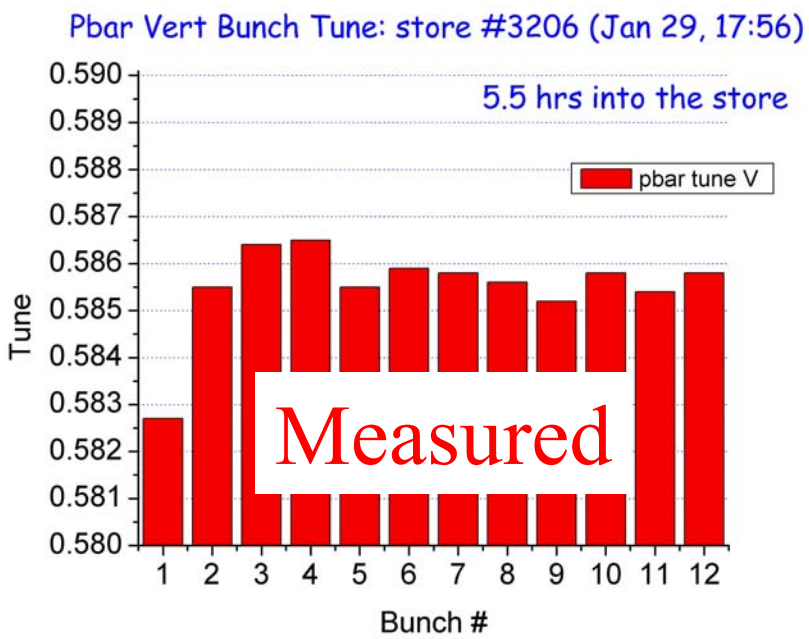
Pbar Tunes Drift Down due to Beam-Beam

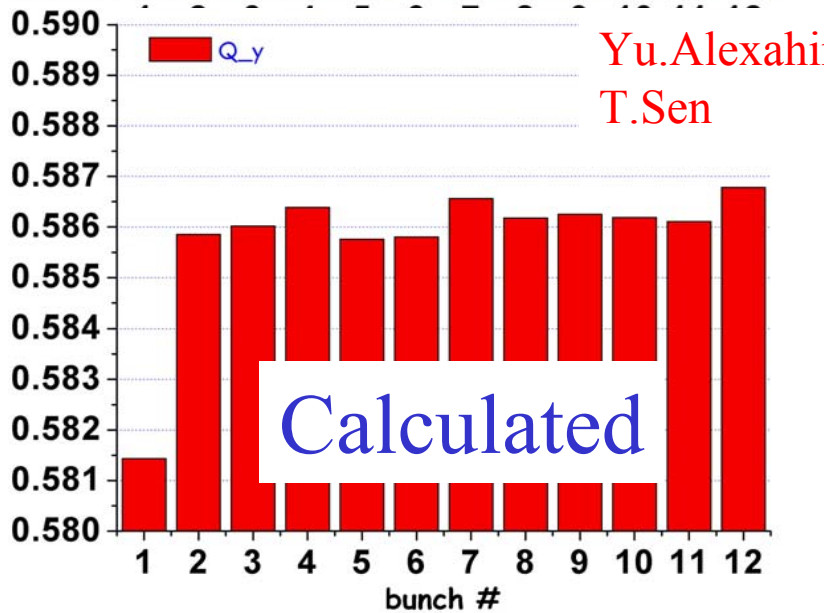


Measured vs Calc'd Pbar Bunch Tunes





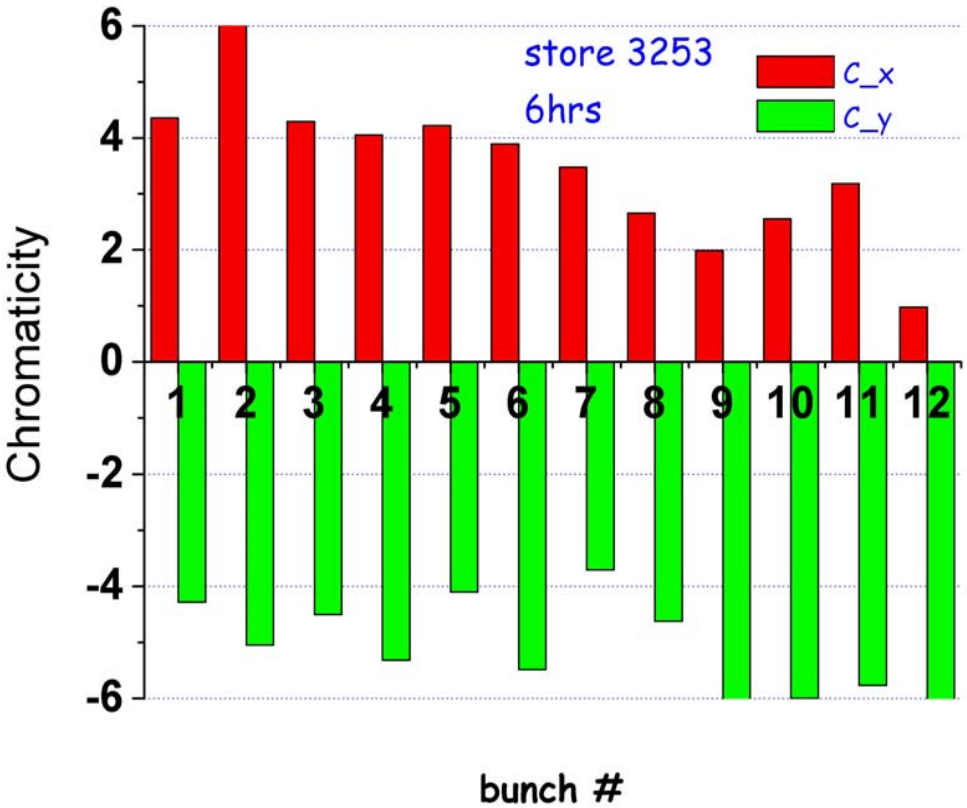


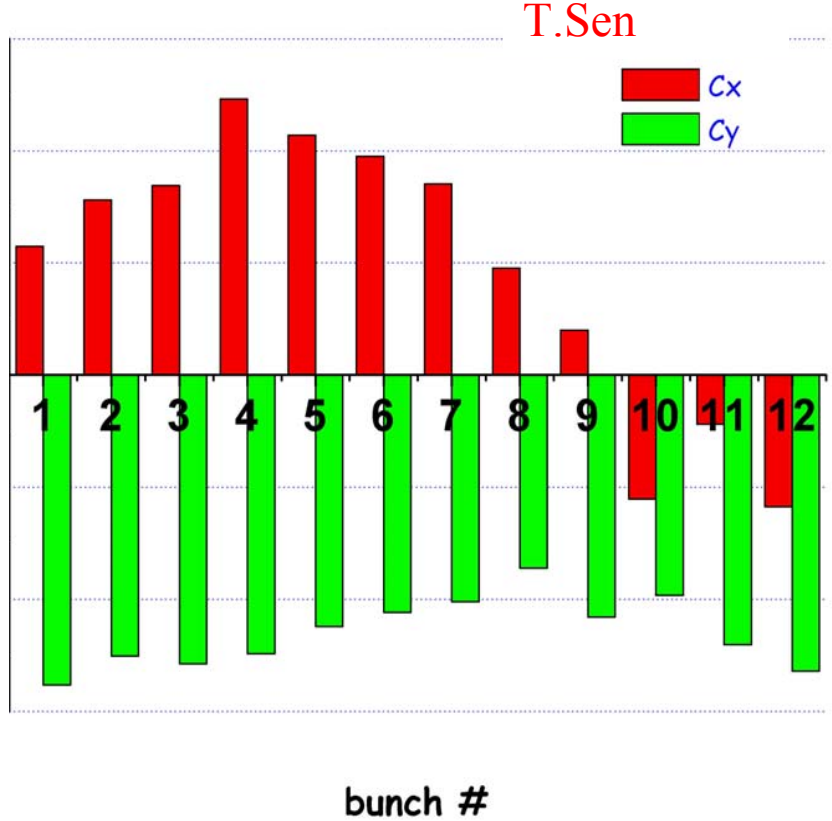


Yu.Alexahin
T.Sen

Measured vs Calc'd Chromaticites

Yu.Alexahin
T.Sen

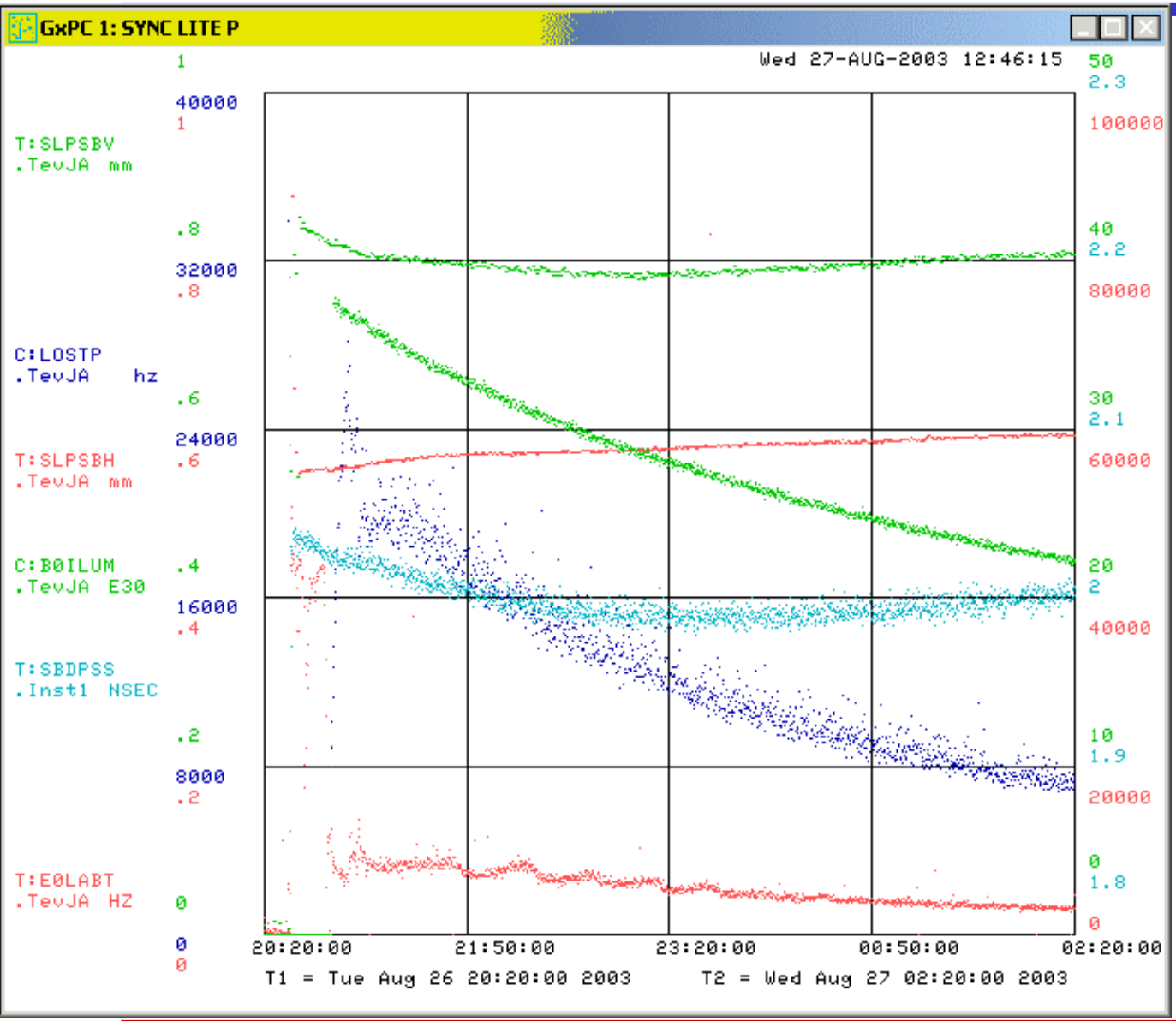




Measured

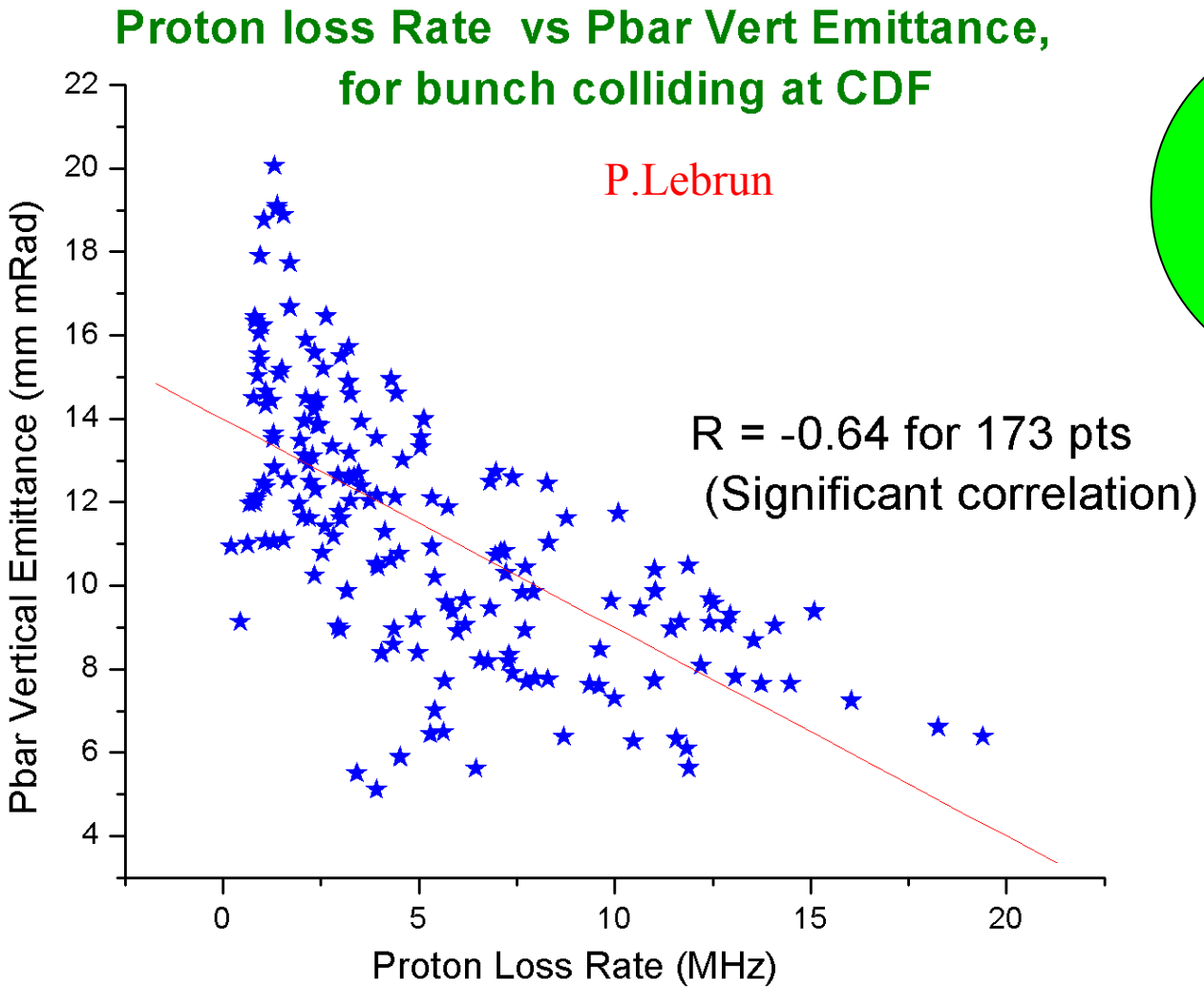
Calculated

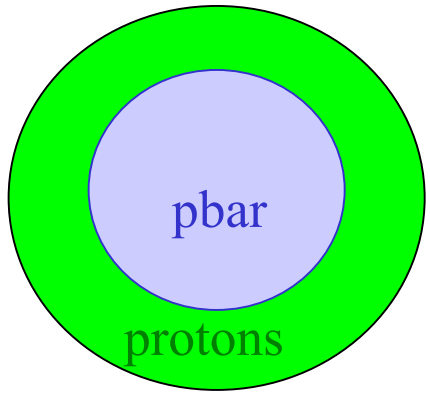
High Proton Losses and Shaving at HEP



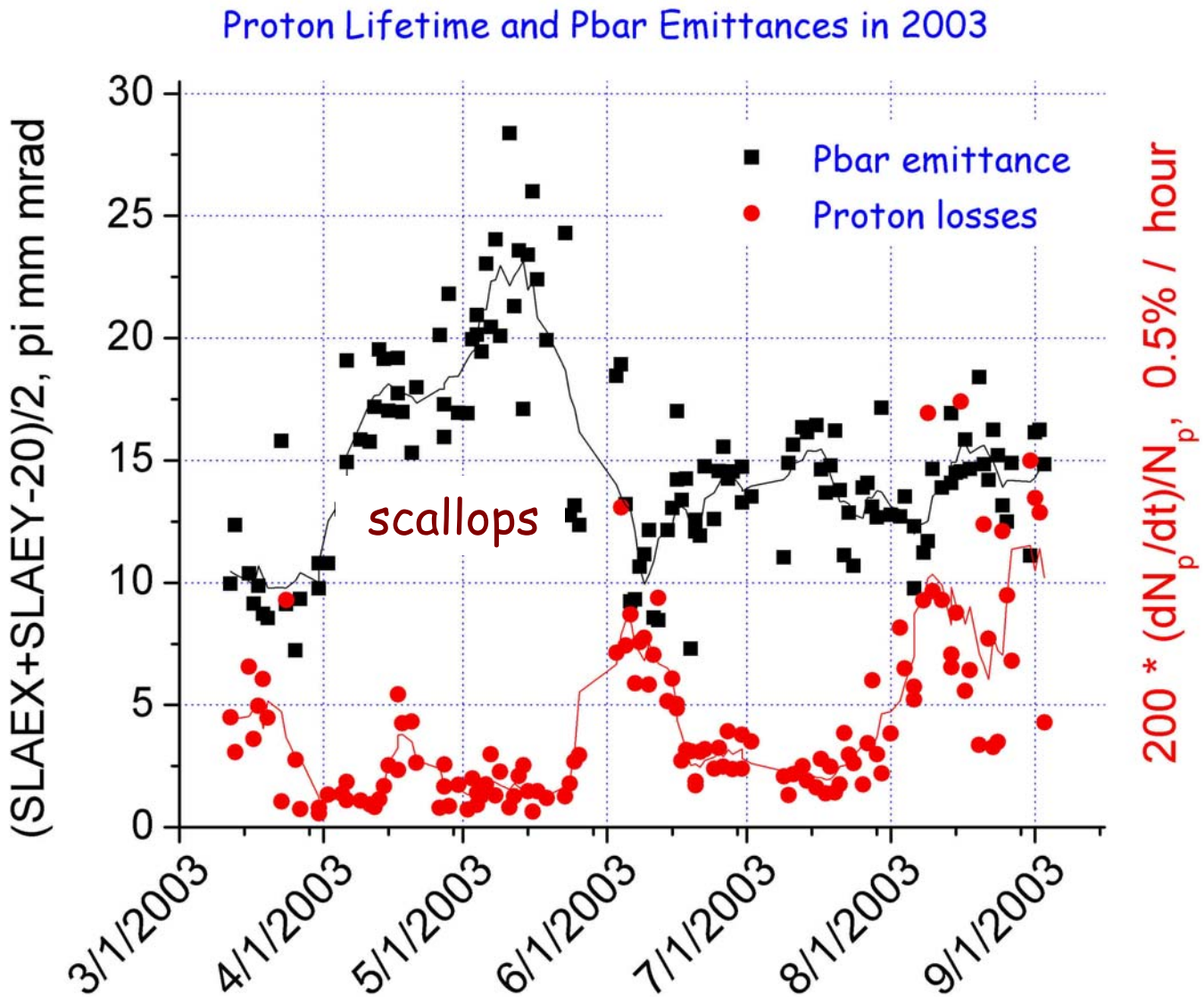
- (re)Started at the end of July'03
- Empirically found that reduced C_v and variation of tunes can help but not drastically
- Cogging scan was not helpful
- Losses >5 times smaller without pbars
- Losses vary bunch-by-bunch ("staircase")

Loss of protons due to pbar non-linearities





Pbar Emittance Matters for Proton Losses @ HEP



These Losses Less of a Problem Now

Reasons:

a) Proton emittance reduced : MI→Tev inj dilution reduced after shutdown, smaller p-emittances from Booster since Jan'04

b) Pbar emittance increased : due to larger stacks we shoot from nowdays

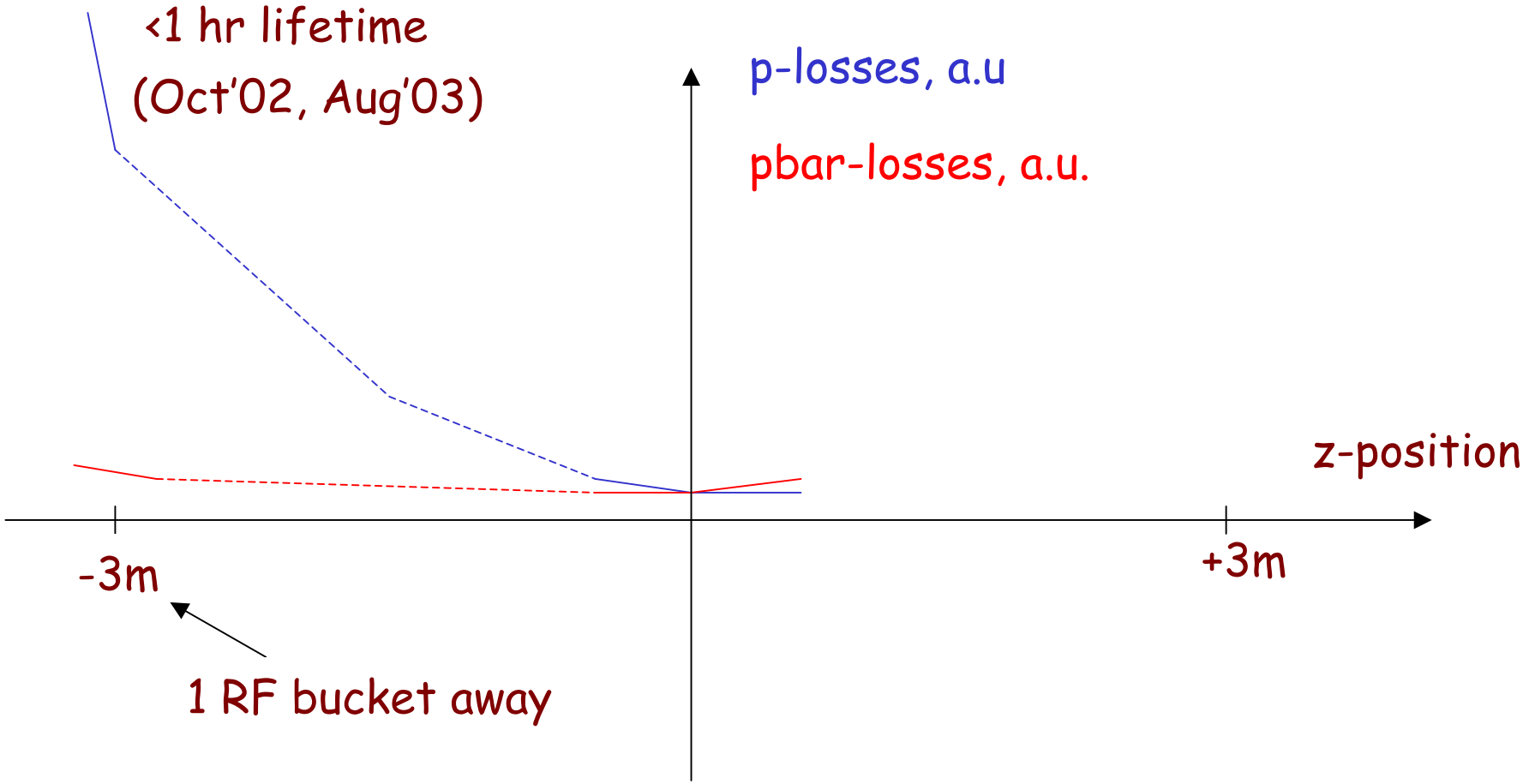
Possibilities for future:

a) Explore wider tune region

b) Shave protons in MI

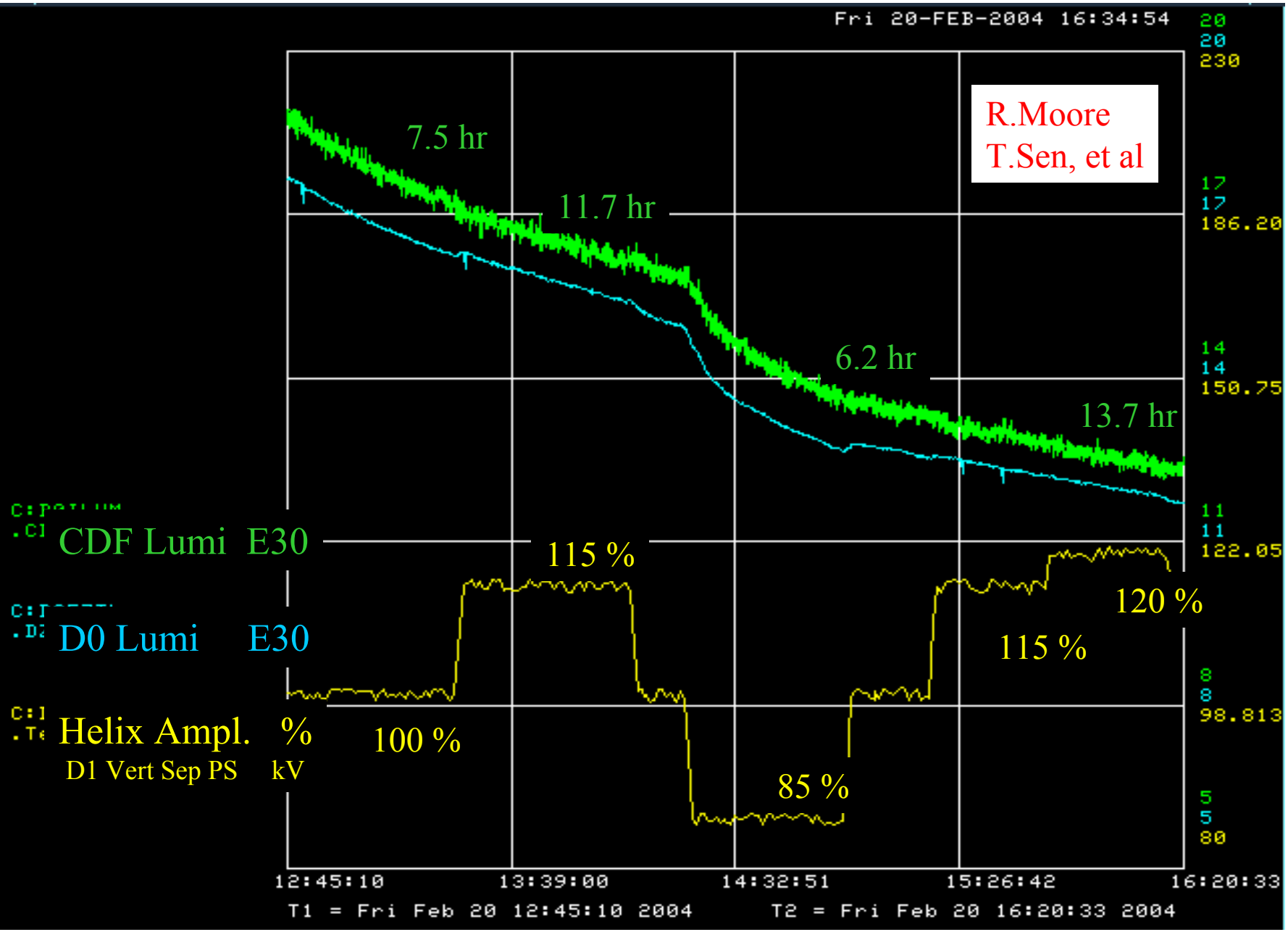
c) BBcompensation

Just Another Puzzle: Collisions OFF-Waist



… need more systematic studies

Luminosity Lifetime vs Helix Amplitude – Store 3247



Understanding Beam-Beam: "Wish List"

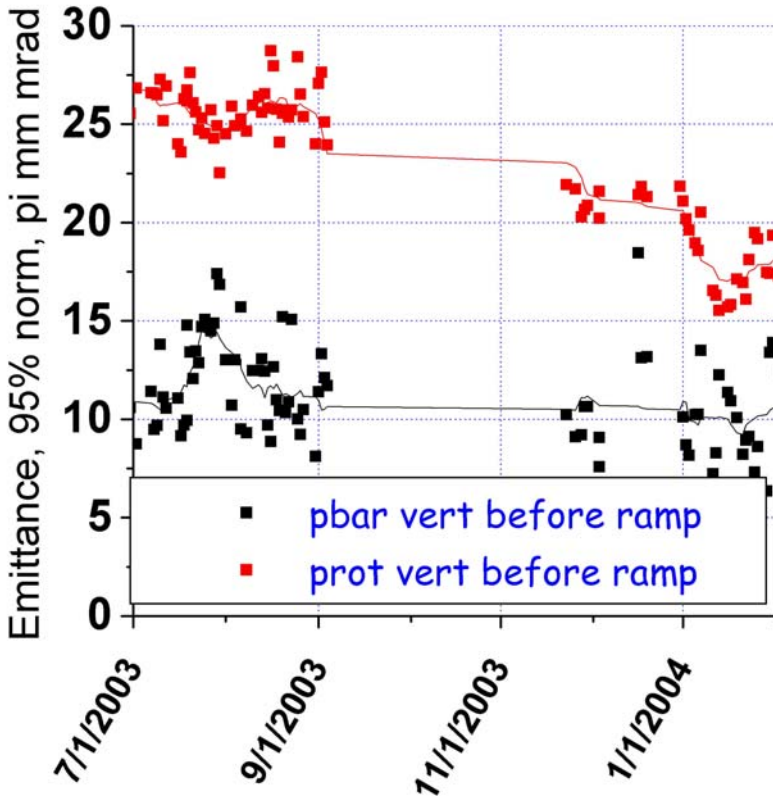
- Simulate Sqrt(Time) and cogging affects at 150
  - Predict aperture/orbit/N_p/N_pbar sensitivity
- Loss on ramp
  - Does it make sense to do final cogging at 150?
- "Scallops" and poor proton lifetime at start HEP
  - Demonstrate in simulations, what matters - Q, C_xy, coupling?
  - consider Run IIU parameters
- Losses vs longitudinal IP position, crossing angle
  - Explain why, set tolerances
- Lifetime(s) vs helix size
- Strong-strong beam-beam – what to expect in RunIIU
- Beam-Beam Compensation – what to compensate, how

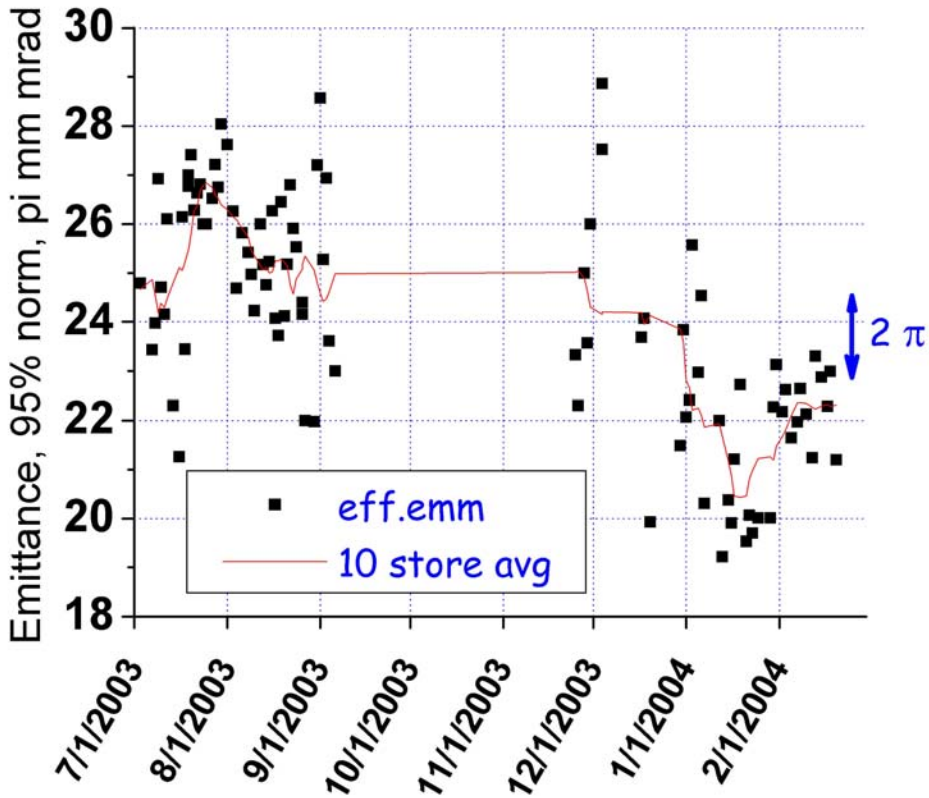
Peak Luminosity Factors

$$L[e30] = 0.17 \frac{N_p N_{\bar{p}}}{\beta^* \left(\varepsilon_p + \varepsilon_{\bar{p}} \right)} H\left(\sigma_s / \beta^* \right)$$

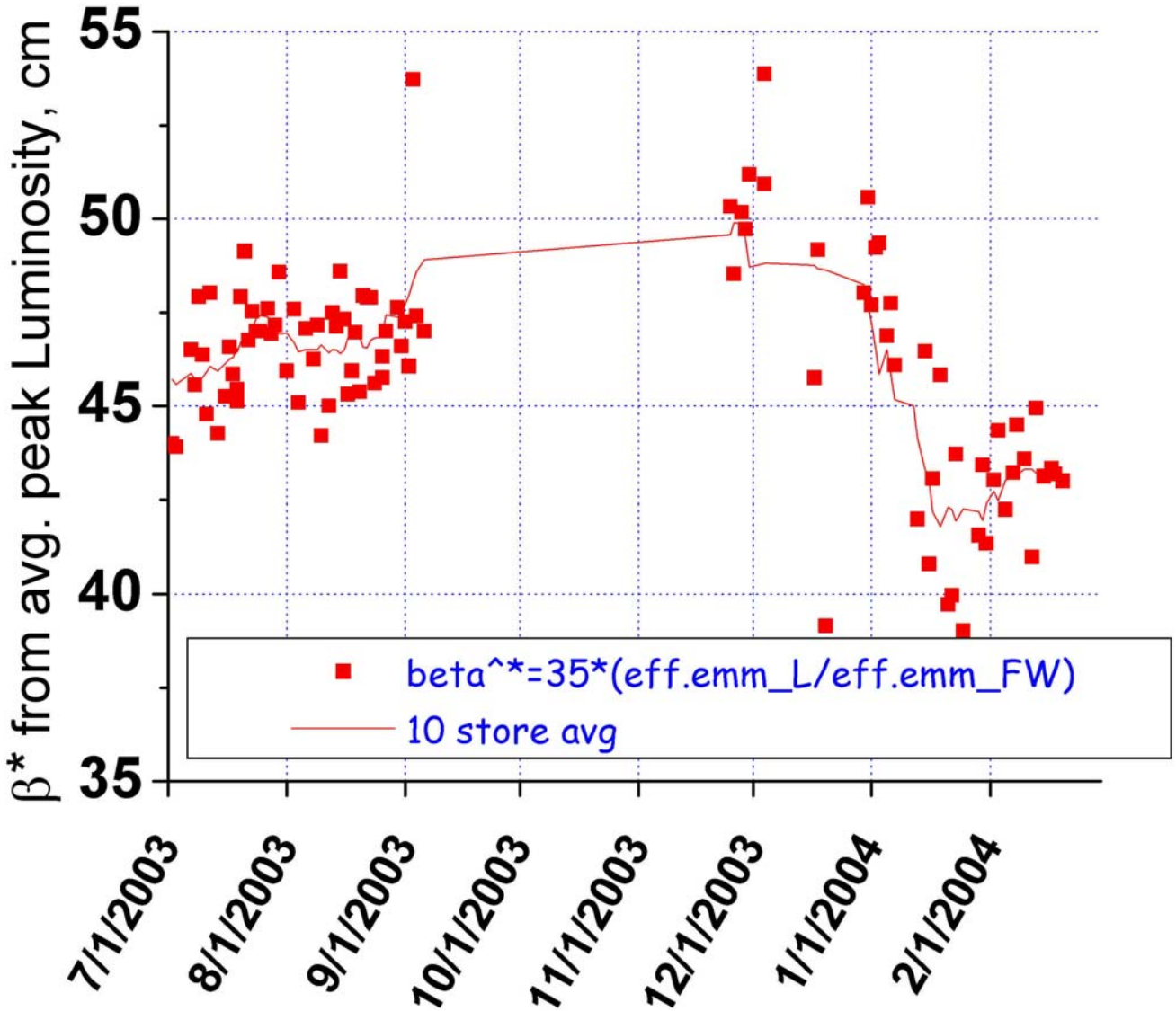
	02/04	FY'04	FY'07
Luminosity, e30	**52**	**62**	**275**
Protons/bunch, e9	**235**	**260**	**270**
Pbars/bunch, e9	**30**	**31**	**127**
Beta at IP, m	**~0.42**	**0.35**	**0.35**
$\varepsilon_p + \varepsilon_{\bar{p}}, \pi$ **μm**	**23+14**	**23+14**	**20+17**
Hourglass	**0.68**	**0.62**	**0.65**

Backup slides 1

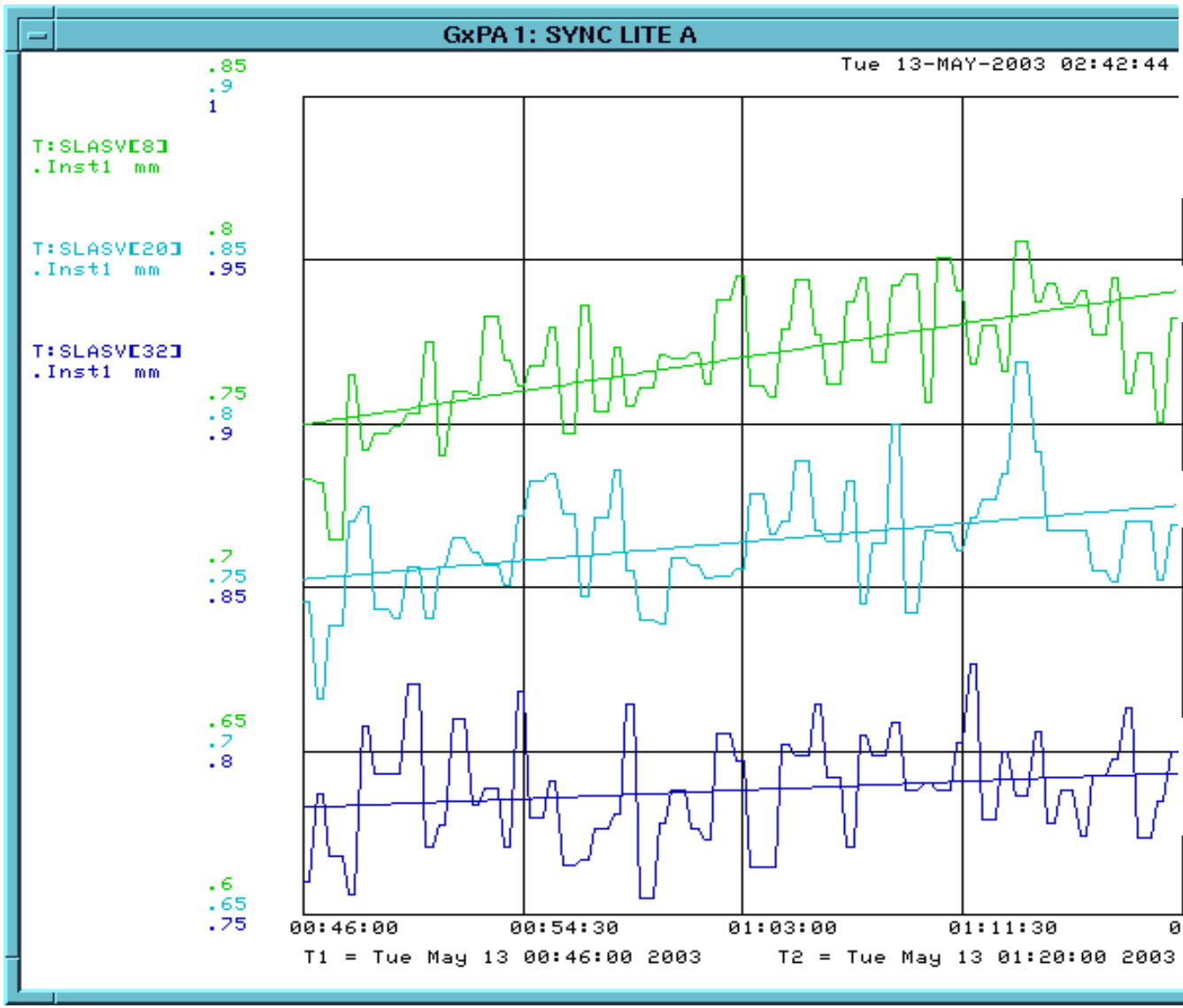




Backup slides 2



TEL Suppresses Pbar V-Size Growth: ½ hr in store



Store #2540

May 12, '03

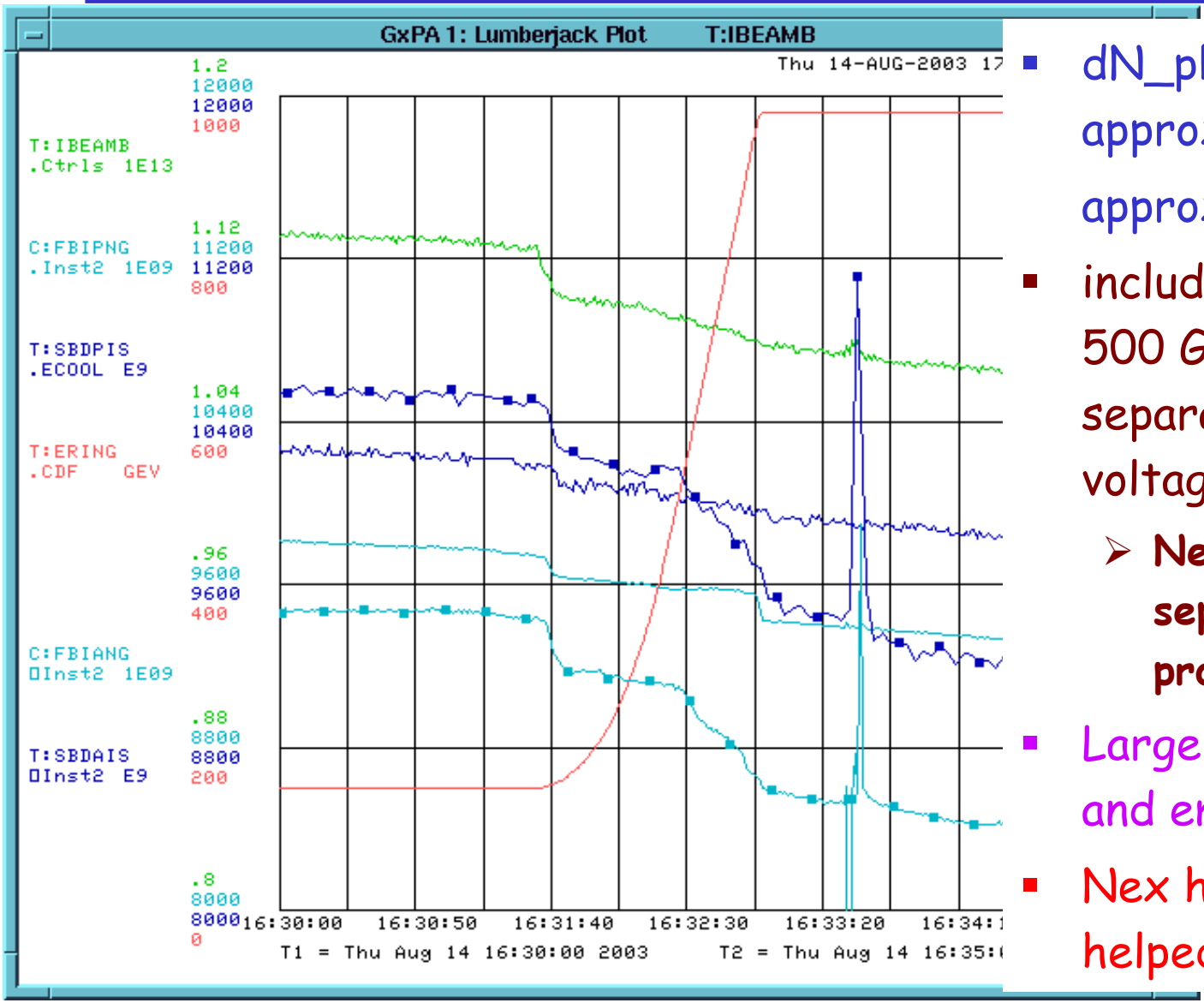
A9 : 4.1 p mm mrad/hr

A21 : 2.2 p mm mrad/hr

A33 : 1 p mm mrad/hr

-TEL on it

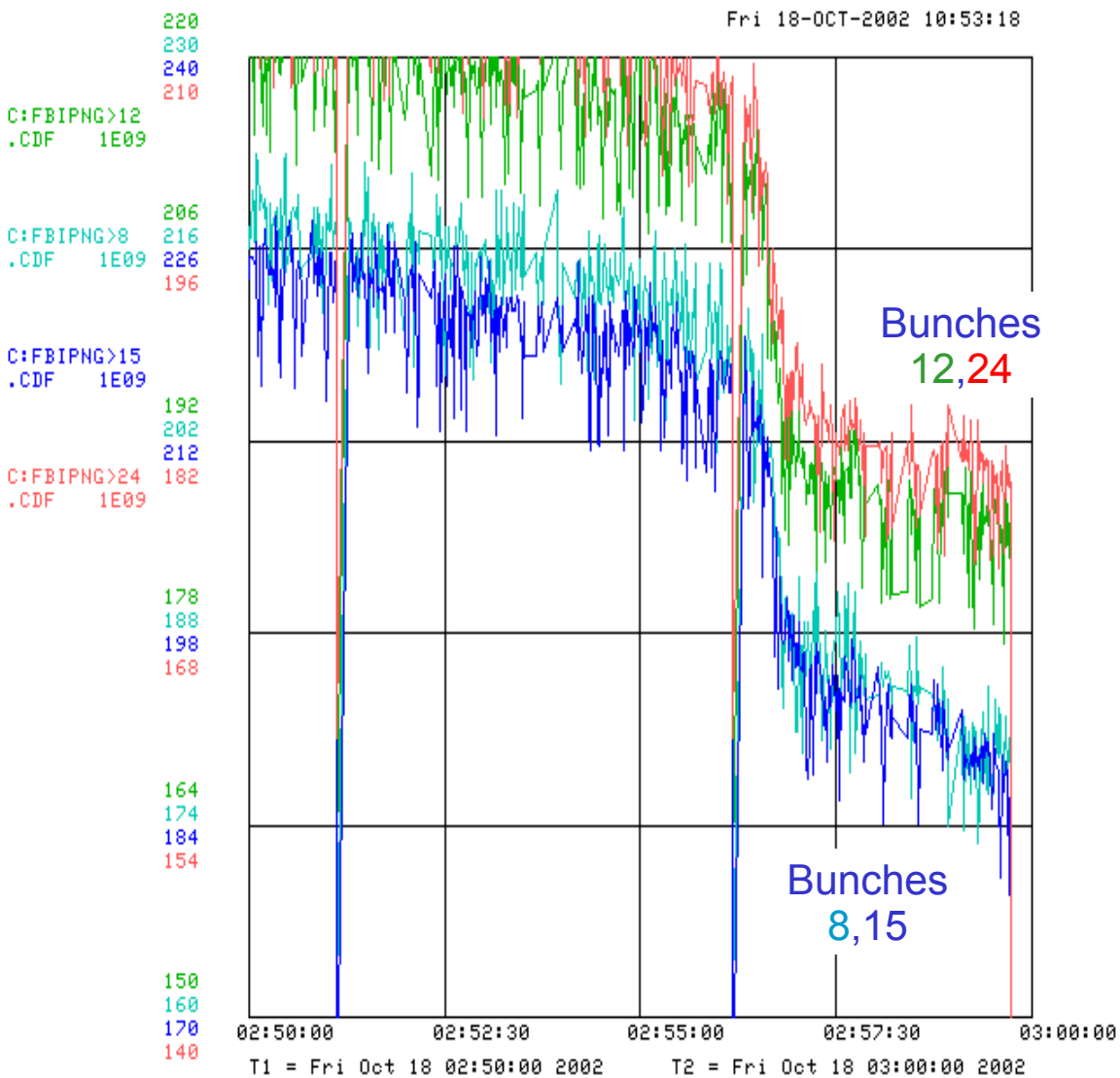
Pbar loss on ramp on Ramp



- dN_pbar on ramp approx 8%

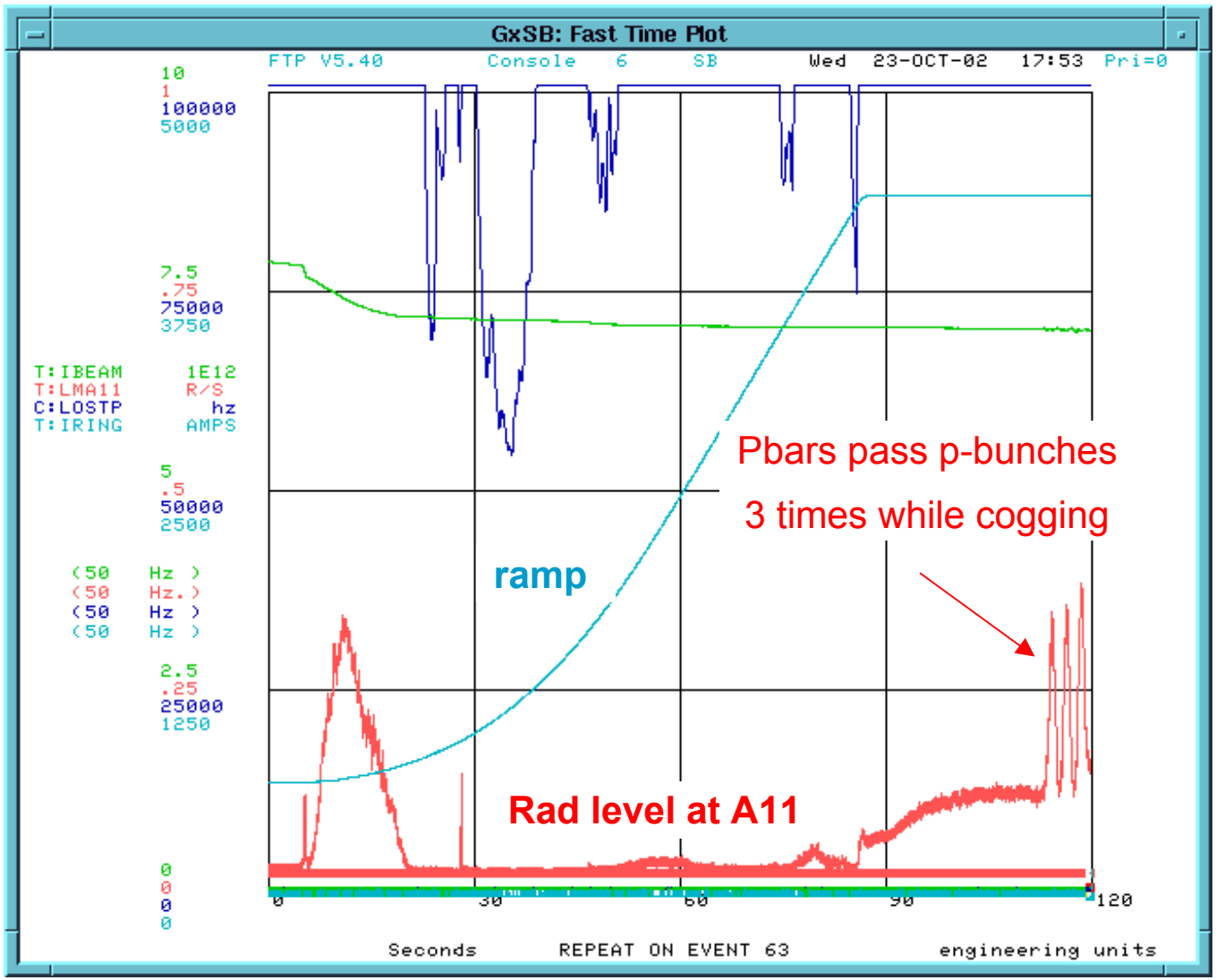
  approx 2% no p's
- including 5-6% above 500 GeV where separators reach max voltage
  - **Need $2^{1/2}$ stronger separators (Run II project)**
- Larger for larger dp/p and emittances
- Nex helix (Sep'03) helped a bit (1-2%)

Beam-Beam Effects in Protons - 2002

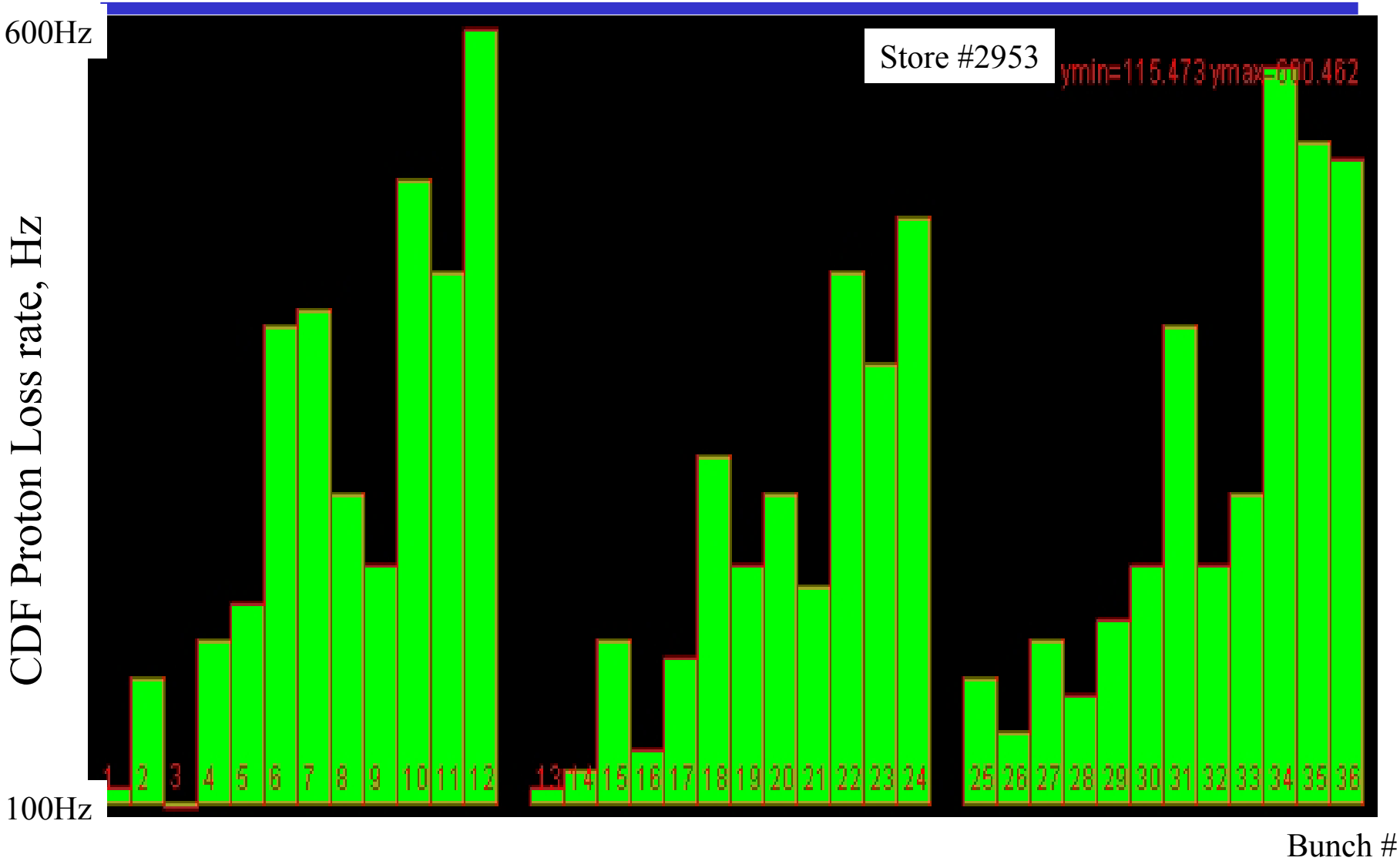


- See losses in squeeze in store #1868
  - Losses of bunches #12,24,36 were small (1e9/min)
  - All other bunches lost intensity very fast (4e9/min)
  - That resulted in quench at A11

Proton Losses While Cogging Pbars

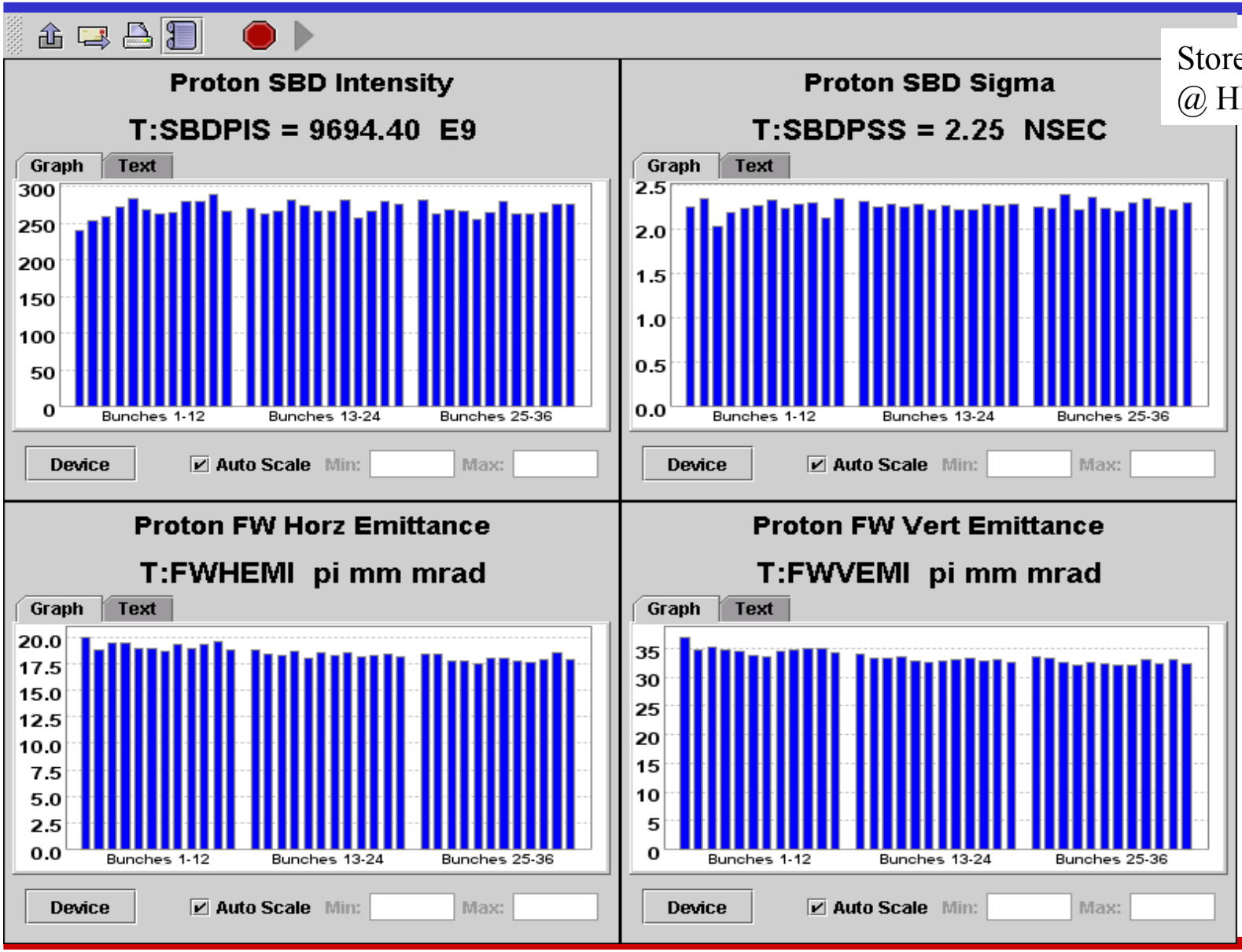


Proton losses induced by Pbars



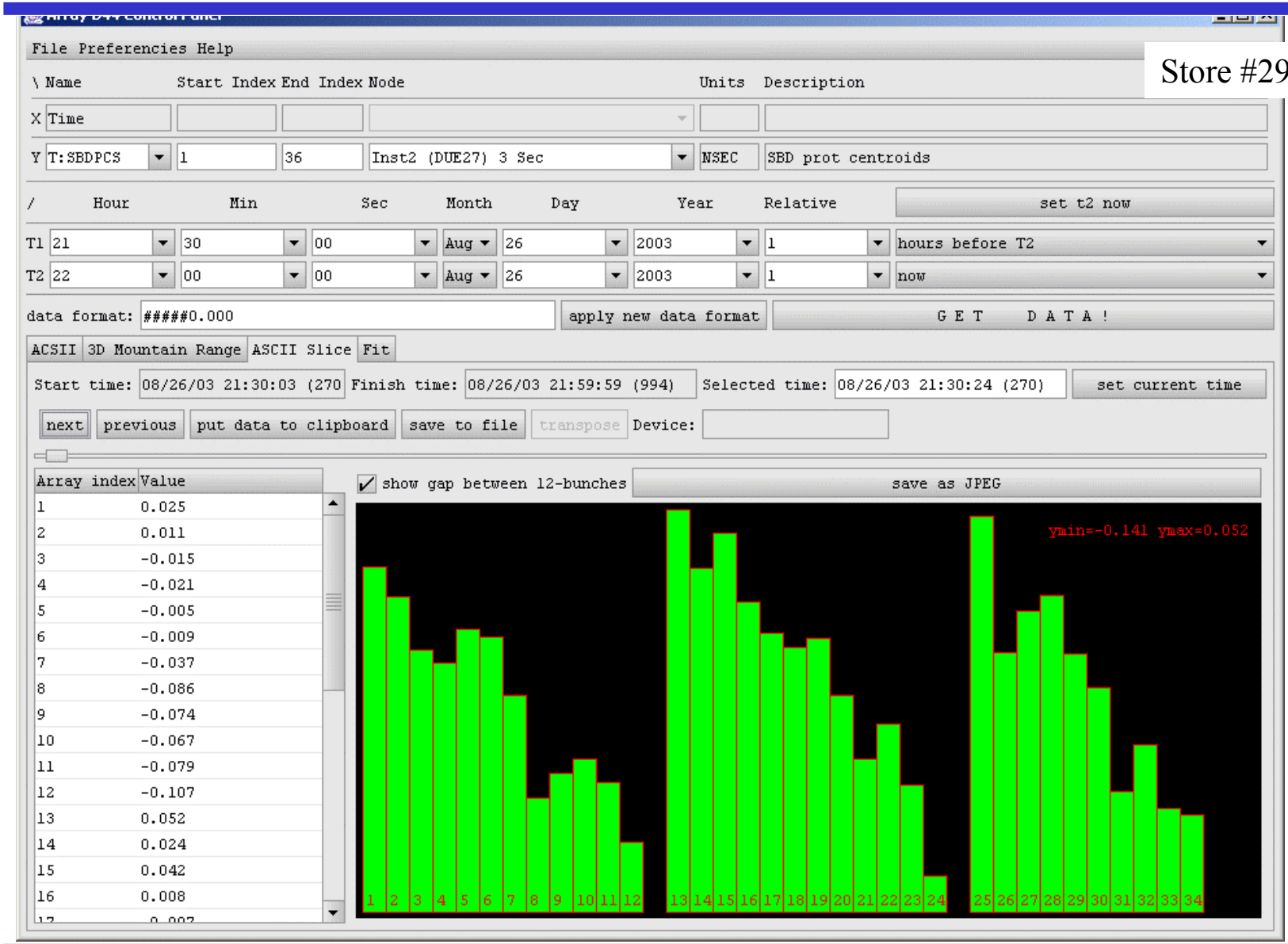
Proton Intensity and Emittances ~Uniform

Store #2932
@ HEP

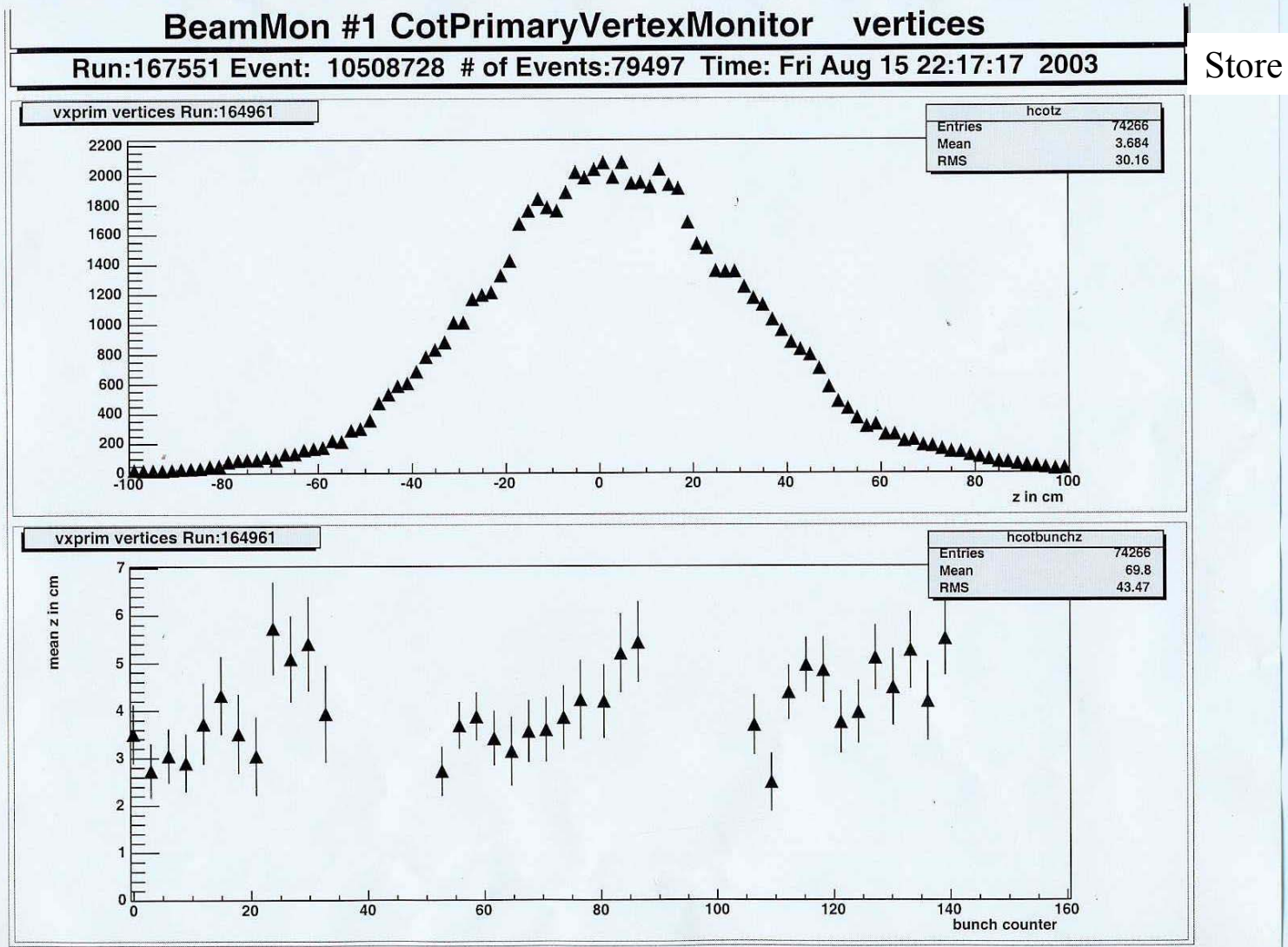


Proton RF Phase - Beam Loading

Store #2953

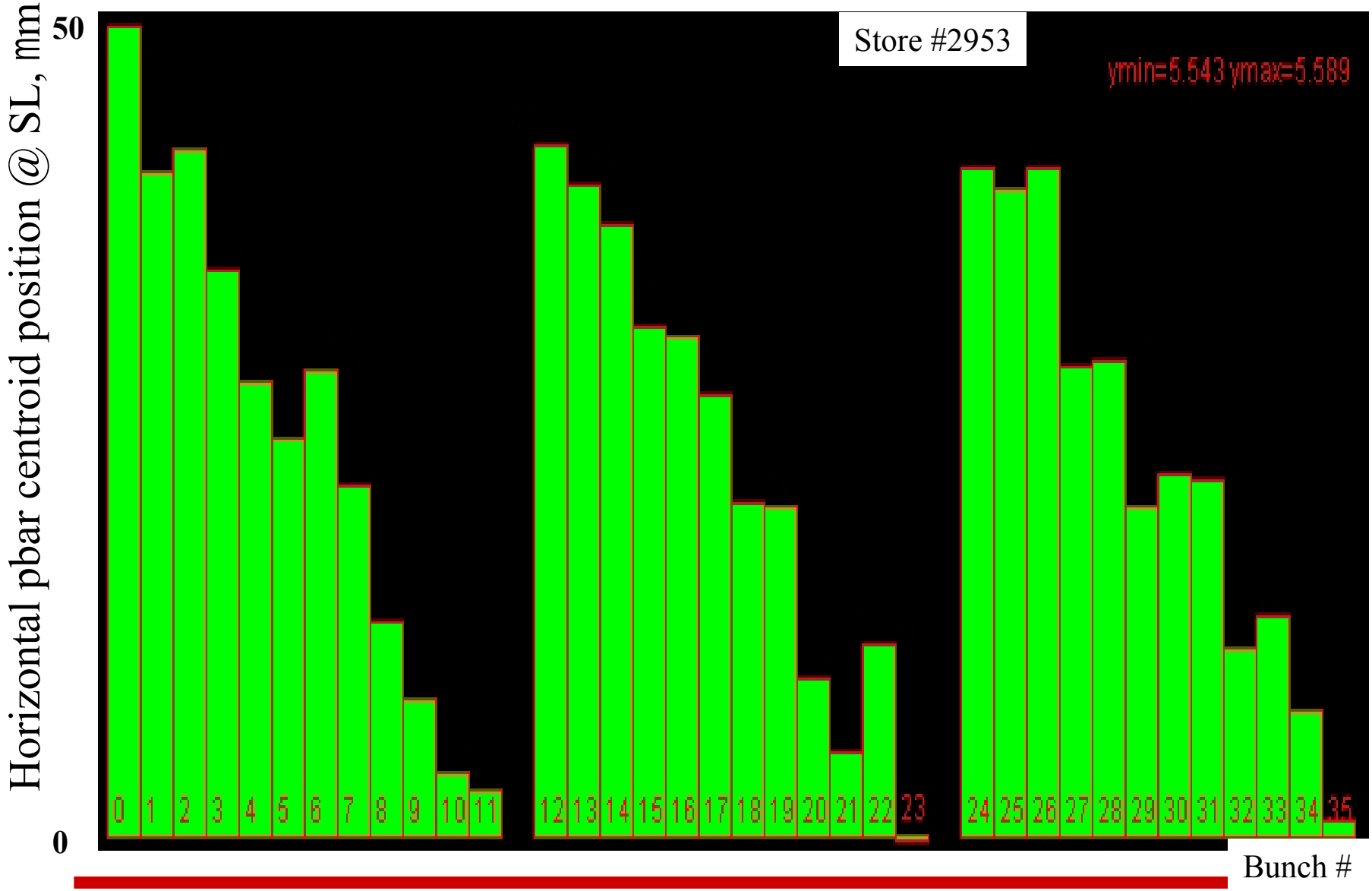


→ results in 3cm variation of IP z-position

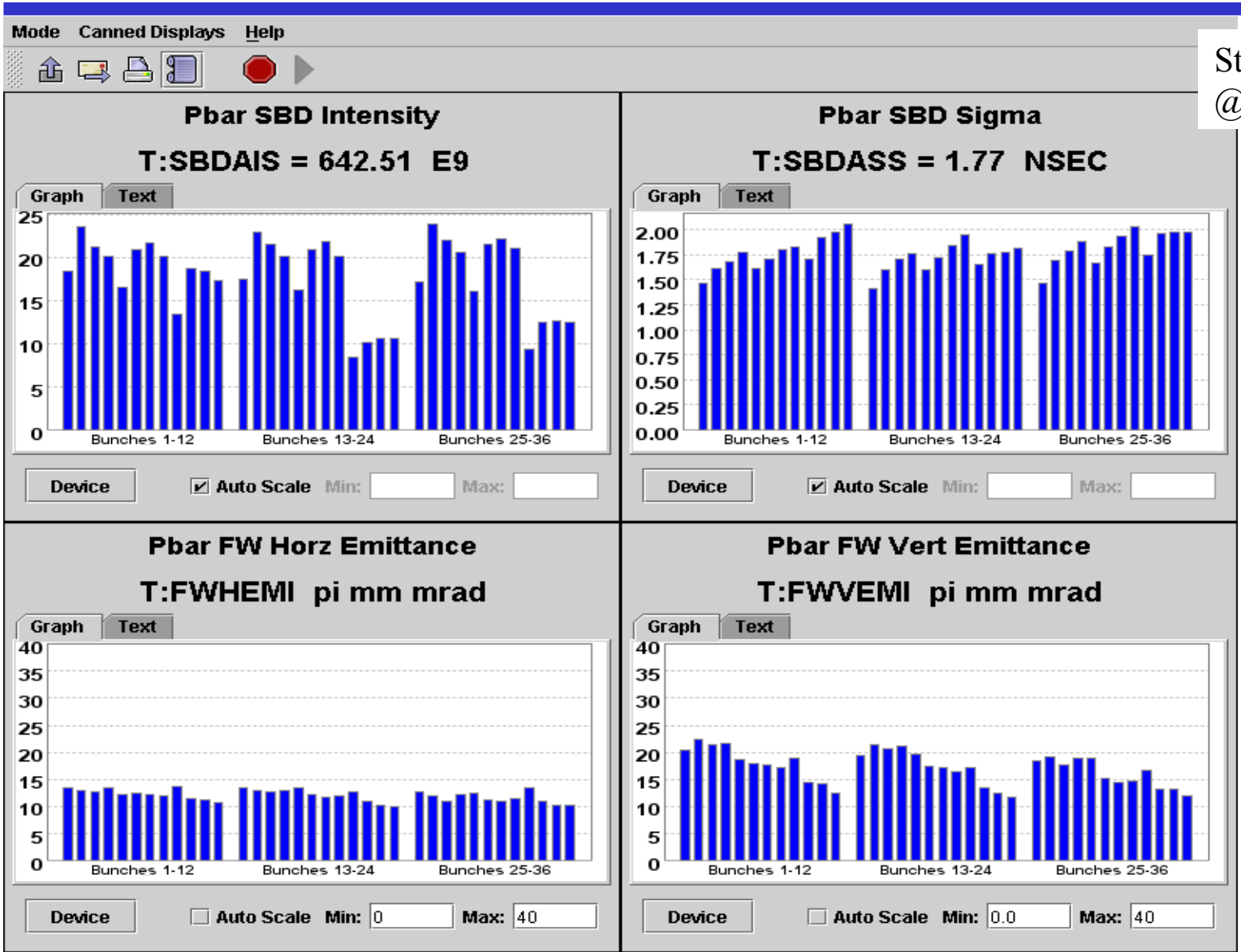


Store #2953

Pbar bunch positions vary due to beam-beam



Pbar bunch intensities and sizes VARY (from AA)



Store #2932
@ HEP